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TRIP PRODUCTION IN URBAN AREAS

A THESIS

Presented to

The Faculty of the Graduate Division

by

William Joseph Fogarty

In Partial Fulfillment

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CHAPTER I

INTRODUCTION

Man seeks understanding of the attributes which govern his behavior. He recognizes that the principles of "cause and effect" underly a portion of his activities. He hypothesizes that it is necessary to quantify, in some manner, the variables which tend to influence behavioral responses. At times such quantification has been found to be of a rewarding nature with the use of predictive models.

Of man's many behavioral patterns, one of interest is that of travel. This thesis deals with vehicular trip production in urban areas.

Description of Man's Travel Desires

In an attempt to quantify travel desires, the description of man's travel patterns is made. Such description results when data related to travel patterns are analyzed. The data collection, quite naturally, is the result of the performance of a survey. The problem which arises in determining which variables to survey comes about because it is necessary to anticipate the end results in order to select the proper variables.

The Collection of Data

The more important travel variables which affect trip production, hence travel patterns, are known in a general sense. However, the specific variables which should be enumerated in a travel study are not known completely. This leads to problems in "proper" sampling and surveying. Since the more important variables which describe trip production are but generally known there is a tendency in data collection to overcollect. "Everything measurable should be measured" is a philosophy which, while providing the necessary data, is the cause of needless expenditures of both time and money. Such an aim results in intolerable data redundancy.

One of the standard surveys performed to collect travel pattern data is known as an Origin-Destination (or O-D) survey. In an O-D study the variables which are measured include all of those believed to influence trip making which are economically measurable. The Origin-Destination survey data serve to illustrate the travel which results from trip productions and attractions.

The quantification of the O-D study data in the past has led to an attempt to define mathematically the vehicular trip production in individual urban areas. Thus, each individual survey has resulted in quantifying trip production and travel patterns for the specific area in which the data were collected.

Present-day techniques for satisfying transportation facilities planning requirements involve describing the present travel characteristics in the community in question. Such description is an estimate at best since the costs involved in 100% continuous sampling are prohibitive at this time. In addition data resulting from 100% sampling are not a requisite for planning surveys. In many instances the need for knowledge as to the character of present travel patterns occurs at a point in time when the data to answer the questions imposed by the need are not available.

For example, if it appears obvious that a transportation link is required to be built, or an existing one to be expanded, it is also required that information regarding vehicular trip production and attraction be made available. These data are available if an origin-destination survey has been completed recently in the urban area in question. Such is not generally the case. Thus, it would appear sensible to conduct an O-D survey prior to building or expanding the transportation link in question. This would, however, be costly in time and money.

It would be most advantageous, in light of the preceding discussion, to be able to discover where similarities between urban areas exist when vehicular trip production or attraction is considered. Most of the work which has been performed in the past in modeling trip productions and attractions by purpose has been done within specific urban areas.

In a study of the literature a conglomeration of discussions relating various attributes of trip production and attraction was found. Several authors have offered equations which purport to describe trip production and attraction potential within specific urban areas or with respect to many urban areas. The equations listed are mostly linear in nature and contain one or more "contributing attributes". That is to say, it is assumed that of the several variables described within the equation, each contributes a share toward trip generation. Unfortunately, in some studies, care has not been taken or the data utilized were too meager to insure that when several variables were utilized in an equation, the variables were not strongly related to each other.

The literature appears, at times, to be contradictory with respect to identification of attributes which are highly correlated, when vehicular trip production or attraction is investigated. In order to discover some of the inter-related attributes a series of preliminary studies of the available data were performed. These studies are described in Chapters IV, V, and VI and in Appendix B. After performing such studies it was concluded that some of the equations exhibited in the literature, on intra-urban levels and on inter-urban levels, contain attributes which are highly correlated with each other.

CHAPTER II

PREVIOUS INVESTIGATIONS

As stated earlier, the literature does not appear to contain an organized progression of findings which lend themselves to presentation in a unidirectional manner. Thus, a summary of the literature cited is presented for a brief look at some of the areas investigated in trip production and attraction. The summary contains the name of the principal author, the attribute(s) being measured and a definition of the inferred attribute(s) utilized in the development of the equation.

Following the summary is a more detailed account of the investigations and the source of the information presented.

Author	Attribute described	Attribute(s) which are utilized in equation
Mertz	Trips per dwelling unit	Family income Distance from CBD Population density Auto ownership
Howe	Movement of people	Zonal labor force Employment opportunity Job availability distance
Hamburg	Trip purpose distribution	Land use similarities between two urban areas

Author	Attribute described	Attribute(s) which are utilized in equation
Sharpe	Trips per resident to and from home	Income
	Total trips per resident	Income
	Population per acre	Income
	Ratio of trips from home to trips from area	Car ownership
Sharpe	Increase in 1955 trips in Washington over 1948 trips in Washington (D.C.)	Increased car ownership
Adams	Mass transit trip production	Transit service ratio factor Land use distribution factor Economic factor
Blumenfeld	Urban travel	Density Distance
Voorhees	Auto shopping trips	Vehicles per dwelling unit
Gorman	Vehicles entering and leaving the CBD	Population
Harper	Person destinations to a zone in the CBD	Floor space
Wright	Trips to CBD by purpose	Floor space
Housten	Driving time	Work trips per thousand in labor force per thousand employees
Voorhees	Commercial non-home based trips	Auto ownership per thousand population
	Social auto driver trips per thousand persons	Auto ownership per thousand population
Cherniak	Person trips per acre	Auto ownership per acre

Author	Attribute described	Attribute(s) which are utilized in equation
Wiant	Work trips	Labor force
	Non-work home based trips	Car ownership
	Total non-home based trips	Car ownership
Levinson	Transit trips per person-day	Persons per square mile
Crevo	Number of recreational trips per family	Car ownership
Voorhees	Trip length	Population
Fisher	Percent workers using auto	Number of autos per household
Barton	Auto driver miscellaneous trips	Dwelling units Car ownership Population Employment

The works of the authors listed in the previous summary, along with other works of interest, are discussed in more detail throughout the remainder of this Chapter.

Carril (1)* discussed the forecasting of traffic in the San Juan, Puerto Rico, metropolitan area with anticipated land use factors. Mertz and Hamner (2) found correlations ranging in value from 0.448 to 0.827 while relating family income, distance from the CBD, population density, automobile ownership, and trips per dwelling unit for 95 zones in Washington, D.C. based on a 1948 Origin-Destination study. Their model for trips per dwelling unit (Y)

*Number in parenthesis refers to bibliographic reference number.

relied most heavily on auto ownership (X) and was given as $Y = 2.88 + 4.6X$. This model had a coefficient of determination of 0.685 and a standard error of estimate of 0.89 trips per dwelling unit.

In the 1957 HRB Proceedings (3) a procedure for forecasting future zonal travel movements based on population, land use and economic activity was outlined. This procedure was oriented toward individual urban areas. In the later part of the 1950's attention was diverted from travel-cause to increased emphasis on trip production models based on physical attraction analogies as well as probability concepts. The data from the Chicago Area Transportation Study was utilized (4) to develop a model basically of the gravity type combined with linear programming techniques for the prediction of zonal movement of vehicles. Howe (5) described a theoretical non-field tested model to describe the movement of people in response to land use variations based upon the principles of electrostatics. The variables used in the model included zonal labor force, employment opportunities and job availability distances. The model was of the stochastic type.

Carroll and Bevis (6) used data from the Detroit Area Transportation Study to forecast the future levels of personal automobile travel in the Detroit area. Following the report, Hamburg (7) compared trip purpose distributions within preselected land use categories for Chicago and

Detroit reporting a "high degree of similarity between the two cities." In a subsequent article of CATS Research News (8) it was pointed out that the pattern of car ownership was "practically the same in both Chicago and Detroit, even while the physical structure of the two cities is considerably different." Sharpe, Hansen and Hamner (9), in 1958, attempted comparison of the two Washington, D.C. origin-destination studies (1955 and 1948). Trends in travel patterns were investigated. Income was the primary variable utilized to evaluate trips per resident to and from home, total trips per resident, and population per acre. Car ownership was related to the "ratio of trips from-home to trips from the area" and a linear relationship was reported. In explaining the increase in 1955 trips per capita over 1948 trips per capita the increase in the auto ownership per 100 persons rate was offered based on data from some 100 zones within the study area. The relationship between auto ownership per person and total trips per capita on a zonal basis was given as being of a linear nature.

In the conclusion of the report Sharpe stated, "Primarily, the results of the study emphasize the fact that traffic is a phenomena of human behavior. It is with people that there should be most concern."

Adams (10), by means of a multiple-regression analysis on data from 16 cities defined factors which related to mass transit trip production. Three factors of significance were reported, a transit-service ratio factor (a function of revenue-vehicle miles operated by the transit system, population greater than five years of age, urbanized land area, average vehicle speed and parking characteristics), a land-use distribution factor (a function of commercial and industrial land areas), and an economic factor (a function of population, employees, dwelling units and auto ownership). No mention was made of the possible correlations between some of the attributes within factors (viz., population-employees-dwelling units-auto ownership interactions and relations which were found in the work of this writer). Blumenfeld (11) in a subjective report hypothesized that distance and density patterns were key variables affecting urban growth and hence, urban travel. Voorhees (12) stated that the ratio of vehicles per dwelling unit was a key variable in his study on auto-travel shopping trips.

Gorman (13) in a study on vehicles entering and leaving the CBD studied several urban areas in a population range of 5,000 to 1,400,000 finding that the increase in CBD oriented trips was not in direct proportion to the population increase. He stated, with regard to CBD oriented trips, "Although population is a very important factor, the variations (of CBD trips) cannot be fully explained by population alone." Harper and Edwards (14) in a study of attractions to the CBD described a method developed to measure the attractiveness of person trips to the CBD. The results of both Origin-Destination and categorized floor-space surveys were utilized. The basis for the developed model included variables for estimating the number of person-destinations in a zone in the CBD to be a function of the area of retail floor space in the zone, the area of service-office floor space and the area of manufacturing-warehousing floor space. The results indicated attractions of trips to be a function of floor space in several types of business endeavors. The model fitted the data well and was linear.

Wright (15) performed a needed extension of the results of Harper and Edwards' study on a larger population scale. More than 90 models were illustrated which related trips to the CBD by purpose. Of the 42 major models listed, ninety percent were linear.

Housten (16) investigated relationships within St. Louis, Missouri, for driving time versus several second-order factors (viz., work trips per 1,000 labor force per 1,000 employees, commercial trips to and from home per 1,000 population per one percent retail sales, social trips to and from home per million population, and off-peak trips per 1,000 school trips per 1,000 population) between zones. His reported relationships appear to be basically linear in nature where such relationships were presented. In investigation of commercial non-home based and social auto driver trips per 100 persons versus auto ownership per 1,000 persons, Voorhees (12) illustrated a linear relationship.

Cherniak (17) in a critique of home interview type O-D surveys showed a linear relationship for person trips per acre and auto ownership per acre on a zonal basis for Chicago.

In addition to such trip attraction studies there have also been trip production studies performed. Wiant (18), in his study of trip production in the Cedar Rapids-Marion urban area, found that (1) work trip production related to the labor force residing in each zone, (2) other home-base trip production was directly related to car ownership, and (3) the total number of non-home based trips produced by a zone was related to total car ownership in the urban area. In summing, Wiant wrote, "Travel patterns similar to those between Cedar Rapids and Marion cropped up in other urban areas with a neighboring satellite community."

In a study which was mass transit oriented, Levinson (19) compared 13 urban areas in a population range of 54,000 to 5.2 million on the basis of trips per person, persons per car, trips per dwelling unit, persons per dwelling unit and cars per dwelling unit. He found a linear relationship between transit trips per person-day and persons per square mile of urbanized area.

Crevo (20) stated that a linear relationship existed between the average number of trips per family and car ownership while studying characteristics of summer weekend recreational travel. Voorhees, et al. (21) investigated trip length and duration as compared to population for 23 urban areas. Auto driver work trips were the subject of study in the population range from 33,000 to 6.5 million. A non-linear decay relationship was discussed. Fisher and Sosslau (22) found a linear relationship between the percent of workers using their auto and automobiles per household in a study of 4,125 zones in the Tri-State Study area.

In an investigation of auto driver miscellaneous trips (trips other than work, shop, personal business) outlined in the Fargo, North Dakota Transportation Study (23), Barton-Aschman Associates found that the trips were a function of dwelling units, cars, population and employment with a coefficient of determination of 0.531 and a standard error of estimate of 104% of the mean.

Throughout the excellent publication, "Future Highways and Urban Growth" (24) the thread of intra-urban relationships is evident with respect to trip production, Linear relationships, to mention but a few, between trips per person-day and persons per square mile, trips per person-day and population, persons per car and trips per dwelling unit are shown. The concept of car ownership, population and congestion is quite evident. Quoting from the publication, "Car ownership and use are related to socio-economic status within the community." Relating this concept to that advanced by Barnes (25) the concept of intra-zonal and intra-urban similarities begins to emerge. Barnes commented that "Car ownership increases as a result of two factors: (a) more cars in the future due to a greater population, and (b) a higher rate of car ownership" (the latter being attributed to higher incomes). Farmer (26) stated, "It is a generally acknowledged fact that there exists a direct correlation between the land use of an area and the vehicular travel desires within that area." It might be added that it is possible that there exists a direct correlation between the population of an area and the land use which tends to produce vehicular travel desires in that area.

In attempting to evaluate the literature a set of questions result:

(1) Would it not seem that propensity to travel is a relatively stable human attribute?

(2) Given the freedom to travel in a basically unrestricted manner will not the population of one area partake in trip making as readily as in another area?

(3) If we consider urban areas on a macroscopic basis, each area being an individual homogeneous entity, what attribute relates most strongly to trip purpose and mode of travel?

(4) If we consider a conglomeration of urban areas on a microscopic basis, say on a zonal level, what attribute relates most strongly to trip production when trip purpose is investigated?

(5) If there exists a relationship of a substantial nature on either or both a macrascopic and microscopic level when trip production is considered, what portion of the expenditure of time, money and manpower can be directed toward the collection of nonrepetitive or basically nonrelated data which will further explain the propensity of persons to travel?

In this respect Bartelsmeyer (27) stated "Data gathering is so expensive and time consuming that indiscriminate collection of facts can be most wasteful, and can cause the technician to lose sight of his real goal, the preparation of a transportation plan." Thus, in answer to the preceeding questions and in an attempt to further define man's travel habits it was decided to investigate the data collected from individual O-D studies of urban areas on a conglomerate basis.

The investigation was broken into two phases, that of a macroscopic nature and that of a microscopic nature. In the macroscopic phase each urban area involved was treated as a distinct homogeneous entity. By use of statistical methods various attributes were compared which might relate to travel. In the microscopic phase each urban area was investigated on a zonal basis to ascertain the interrelationship between various attributes. After determining that, for each individual urban area, similar relationships existed on a zonal basis, all zones from all areas were combined for totalized analyses.

Natural events are simple after basic cause and effect are uncovered. It might follow that a basic measuring unit or set of basic measuring units could be available to help in quantification of trip production. The first basic measuring unit that might come to mind which possesses the property of basic simplicity is population. Others might include car ownership, dwelling units, labor force, income and employment.

CHAPTER III

DATA COLLECTION

In order to investigate the possibility of an interaction between trip production and some definable attributes, a series of completed Origin-Destination Surveys were requested from various State Highway Departments. Specific studies were requested to satisfy two hypotheses discussed below.

It was assumed that an upper limit should be placed on the population represented by the urban areas to be investigated. This assumption was predicated upon the hypothesis that, when the population of an urban area exceeds some limit, the propensity to travel is reduced. Travel production trends could be masked by congestion, the congestion being produced by a lack of adequate facilities by which to satisfy inherent travel desires. This does not mean to infer that areas of large population are necessarily congested, or that areas of lower population are not congested. It is simply offered as one of the possible causes of lessening travel desire. The point is further discussed in Chapter IV. It was necessary to test this hypothesis and, if adequate proof could be offered, the upper limit could be set.

Secondly, it was deemed necessary to secure data in which similar judgment had been utilized in defining the measured characteristics. The data should, further, represent urban areas of differing social, economic and geographic makeup. This would allow testing the second hypothesis that a basic measuring unit of nature, population for example, is that which reflects a high degree of correlation to trip production. By selecting urban areas of differing social, economic, and geographic makeup it was assumed that the second hypothesis could be justified, given that the trip production attributes of the chosen urban areas showed marked similarity. In addition, it was assumed that the data should have been collected utilizing similar definitions for each trip purpose. The logical answer to this requirement was to utilize data taken by a single study agency or consulting firm. The firm of Wilbur Smith and Associates was chosen as that one which would satisfy these requirements.

Figure 1 shows the distribution of SMSA's* throughout this country while Figure 2 indicates the distribution of O-D study areas which were utilized in some manner during the course of this study. Figure 3 is a histogram indicating the number of study areas which fell into specific population groupings.

The O-D study areas indicated on Figure 2, moving

*Standard Metropolitan Statistical Area

from west to east are as follows:

Anchorage, Alaska
Eureka, California
Truckee Meadows, Nevada
Las Vegas, Nevada
Salt Lake City, Utah
Casper, Wyoming
Denver, Colorado
Albuquerque, N. Mexico
Rapid City, S. Dakota
Sioux Falls, S. Dakota
Kansas City, Kans.-Mo.
Little Rock, Arkansas
Lake Charles, Louisiana
St. Louis, Missouri
Bowling Green, Kentucky
Hopkinsville, Kentucky
Nashville, Tennessee
Huntsville, Alabama
Chattanooga, Tennessee
Knoxville, Tennessee
Asheville, North Carolina
Tampa, Florida
Columbia, South Carolina
Charlotte, North Carolina
Baltimore, Maryland
Boston, Massachusetts
Lewiston-Auburn, Maine

In a few cases data from studies not performed by Wilbur Smith and Associates were utilized. Some of the data, especially that representing the larger study areas, were used only to justify the use of an upper-limiting population as discussed earlier.

The Burroughs 5500 high speed computer located on the campus of the Georgia Institute of Technology was utilized as a tool in performing the basic arithmetic steps required to statistically treat the data. The programs which were utilized consisted of a library program for performing standard regression-correlation analyses and an X-Y plot program built by the writer to graphically illustrate data.

Figure 1. Standard Metropolitan Statistical Areas, 1960

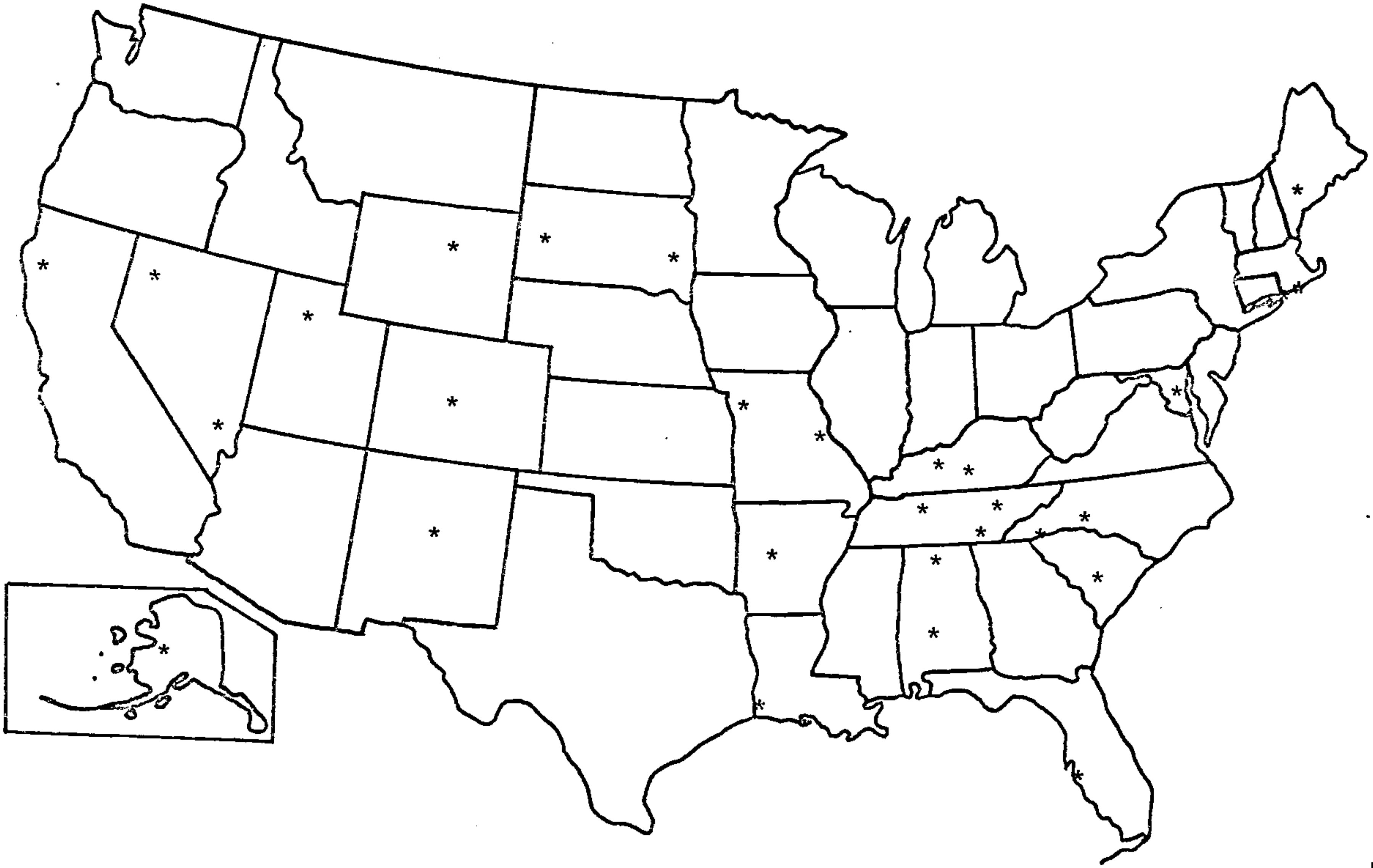


Figure 2. Geographic Scatter of O-D Study Areas

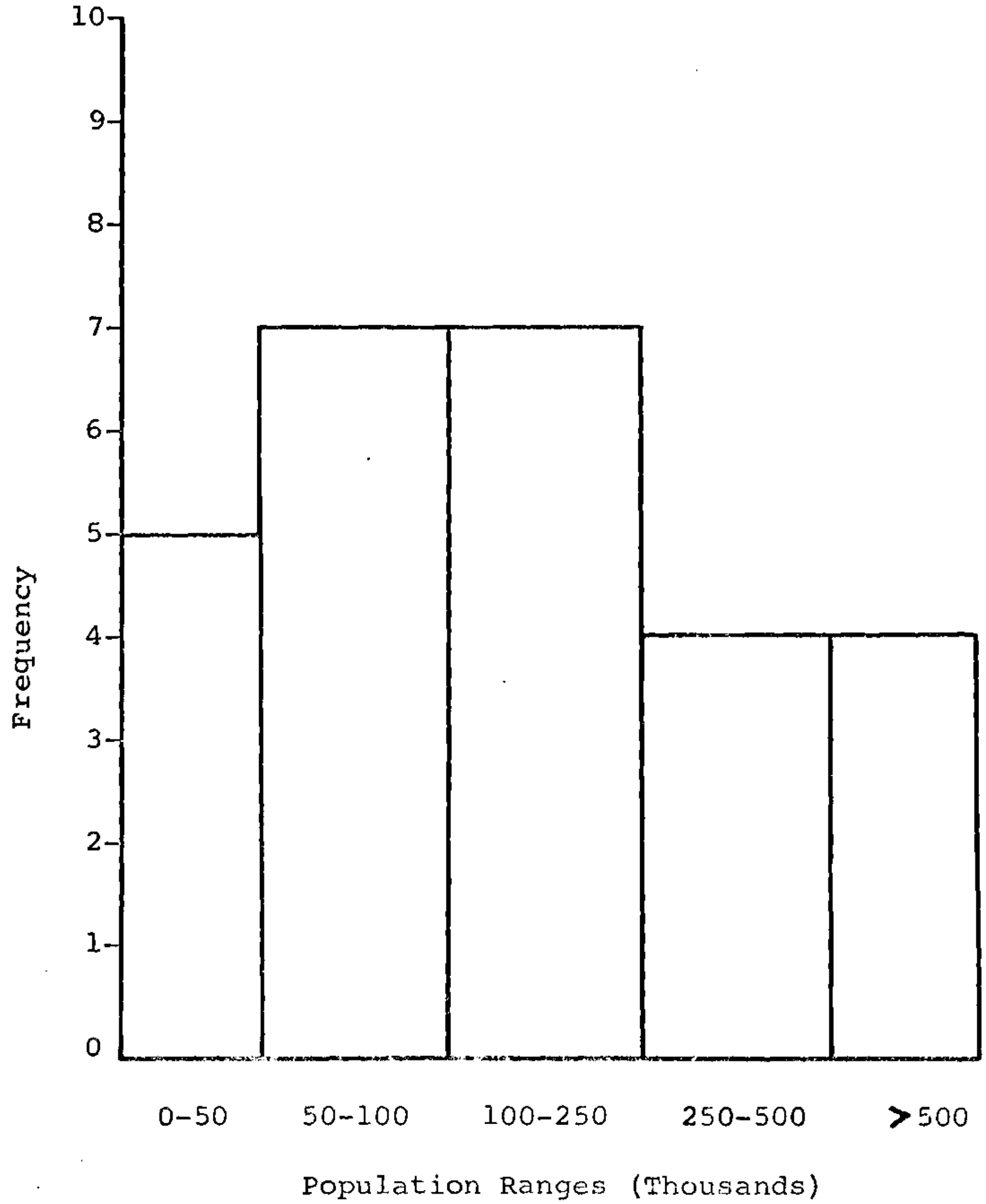


Figure 3. Histogram of O-D Study Area Populations

CHAPTER IV

RATIONALE

An analysis was performed as an initial study to attempt to define the upper population limit previously hypothesized. In plotting a series of curves, of trip volume by various modes and for various purposes versus population, the trend indicated in the Wilbur Smith publication "Parking Guide for Your Cities", as well as that shown by Wright (15) was verified. The trend appears to be of such character as to indicate a departure from linearity for trip volume versus population at population values greater than 750,000. It was concluded on the basis of the results of the study that there does, indeed, exist some population range beyond which the travel production rate of an urban area seems to be reduced. The amount of data available over this higher population range was not deemed sufficient in quantity to do more than to indicate that, as population increases through and beyond the population range of 750,000 to one million, trip propensity is no longer linearly related to population in the same manner as within the population range of 50,000 to 750,000. Gorman (13), in a study of CBD trips, voiced agreement with this concept. For this reason, the upper limit of study population was set, by judgment, to be in the neighborhood of 800,000.

The existence of this hypothesized upper limit can be argued on the basis of loss of homogeneity, transportation system capabilities, or contribution of a lessened desire to travel induced by the psychological impact of large numbers and proximity of competing travelers (28).

It was determined that the research would be performed on two levels of study. The uses of such types of study are discussed at the end of this chapter. On the first level, the macroscopic level, each urban area was looked upon as an individual entity contributing, for any one investigation, but one piece of data. Some of the studies utilized contained more depth than other studies when data enumeration was considered. Thus, there were times throughout the macroscopic level of investigation when data from more than twenty urban areas were available for comparison. In other instances the data were available from less than fifteen urban areas due to the scope involved in the studies.

On the second level of the research, the microscopic level, data representing zonal characteristics within the respective urban areas were investigated. There were two phases to this level of study. In the first phase each urban area was separately investigated with respect to zonal characteristics. Each zone within a particular urban area was looked upon as an individual entity contributing, for any one investigation, but one piece of data. In the second phase all zones from all respective urban areas were combined for analysis with each zone, now irrespective of its location or identity, contributing one observation to the investigation.

Of the uses of such information as might result from the two levels of investigation the prime use for a transportation planner would be that of eliminating costly data collection in order to secure data for estimating transportation needs for an urban area in toto or for a specific zone within the urban area. By being able to predict an "average" value (as determined by a developed equation) and comparing it to an "actual" value (as measured in the field) the need for a study might be determined. Such comparisons, while not always indicating remedial action undoubtedly allow a planner the opportunity to better understand the attributes of zones within his jurisdiction.

CHAPTER V

MACROSCOPIC INVESTIGATION

The macroscopic level of study involved analysis of some of the socio-economic attributes of urban areas measured on O-D studies. The initial investigations on the macroscopic level were made involving some attributes which are generally believed to be closely related. The offer of proof of such a relationship may be cited from past literature or justified on an intuitive basis. In order to preclude the possibility of faulty intuitive reasoning and to recheck some of the earlier findings reported the relationships between commonly reported attributes were investigated. These attributes were investigated in three preliminary groupings (Dwelling Units, Economic Attributes, Population).

Dwelling Units

The relationships between Total Dwelling Units, Rented Dwelling Units and Owned Dwelling Units were investigated with respect to correlations between the attributes. In ten of the studies data were given with respect to a breakdown of dwelling unit data in the form of total dwelling units, rented dwelling units and owned dwelling units. An investigation of the relationship between the three descriptions of dwelling units yielded the matrix of correlation coefficients shown in Table 1.

Such a matrix of correlation coefficients as shown in Table 1 is of the symmetric variety with a principle diagonal of unity. To avoid duplication in the remaining presentations only the lower triangular matrix of correlation coefficients will be presented. To interpret the matrix, total dwelling units correlates with owned dwelling units at 0.9969 and with rented dwelling units at 0.9996. The other correlation of interest is that of owned dwelling units with rented dwelling units at 0.9988. The interpretation of the unit diagonal is an explanation of correlations of specific attributes with themselves.

Table 1. Dwelling Unit Correlation Coefficients Relating Total, Owned and Rented Units

Total Dwelling Units	1.0000	0.9969	0.9996
Owned Dwelling Units	0.9969	1.0000	0.9988
Rented Dwelling Units	0.9996	0.9988	1.000

From the indications of such high correlations it might be concluded that it would be possible, on a planning level, to arrive at an initial estimate of an urban area's "rating" with respect to dwelling unit characteristics. If the ratio of owned to rented dwelling units in an urban area in question was significantly different from that which might be expected, then an indication for the need of a dwelling unit survey would be evident. Such is the value of most trend-type expressions, they serve to give indications of areas of study needs.

Employment-Labor Force-Dollar Retail Sales

The labor force description used here is defined as consisting of those who are willing and capable of working in some capacity and reside in the study area. Employment is a measure of jobs or positions currently being filled in the study area. Dollar Retail Sales is self defining.

A study of the three attributes shown in Table 2 for sixteen urban areas yielded the correlation matrix shown below.

Table 2. Correlation Coefficients Relating Employment, Labor Force, and Retail Sales

Employment	1.0000		
Labor Force	0.9924	1.0000	
Dollar Retail Sales	0.9879	0.9693	1.0000

Such correlation values indicate strong relationships in the urban areas studied among the respective attributes shown.

The correlation coefficients given in Table 2 are for aggregates (viz., employment, labor force, dollar retail sales). These "aggregates" might be considered to be "first order" relationships when compared to rates or "second order relationships". A second-order relationship is defined here as being a rate-type statistic which includes not one, but two (or more) variables. In investigating the correlation coefficients which exist between employment per 100 population, labor force per 100 population, and dollar retail sales per 100 population the data illustrated in Table 3 resulted.

While the coefficient of correlation between the first two attributes has become less attractive it is still reasonably high. Such is not the case with the correlation coefficients between the Dollar Retail Sales per 100 Population rate and the other rates.

In order to investigate further the employment-labor force relationship a standard regression-correlation analysis was performed after the data had been plotted. It was deemed necessary in all cases associated with this research to plot the data prior to regression analysis in order to make a meaningful choice of the form of equation to utilize in "fitting" an equation to the data. The results of the employment-labor force analysis are graphically illustrated in Figure 4.*

Table 3. Correlation Coefficients of Employment, Labor Force and Retail Sales Rates Per 100 Population

Employment/100 Population	1.0000		
Labor Force/100 Population	0.8460	1.0000	
Dollar Retail Sales/100 Population	0.0513	0.3667	1.0000

Population Greater than Five Years of Age

An analysis of twelve urban areas with respect to population, population greater than five years of age and population greater than five years of age making trips yielded the correlation matrix shown in Table 4.

Table 4. Population-related Correlation Coefficients

Population	1.0000		
Population greater than five years of age	0.9992	1.0000	
Population greater than five years of age making trip	0.9988	0.9985	1.0000

*Figures 4-63 are illustrated in Appendix A.

After plotting the data describing population versus population greater than five years of age making trips, a regression-correlation analysis was performed. The resulting equation and associated measures of "fit" are presented in Figure 5.

Population and Social-Economic Attributes

Investigation within the following groups on an individual basis had been performed at this point:

Group I: Dwelling Units (Total, owned, rented)

Group II: Population (Total, greater than five years of age, greater than five years making trip)

Group III: Economic (Labor force, Employment, Dollar Retail Sales)

After ascertaining that there appear to be strong relationships within the various groups, the next task was to attempt determination of interrelationships among various attributes of the study area. Five major attributes were chosen for this investigation as taken from twenty-two urban area studies. The population range represented was from 26,000 to 860,000. The attributes measured were total dwellings, total population, car ownership, employment, and median income.

The resulting correlation matrix shown in Table 5 was secured and after plotting the data the equations illustrated in Figures 6, 7, and 8 were developed.

In plotting population versus median income it was interesting to note the appearance of a geographic influence at small populations. For larger populations the effect of geographic location tends to be eliminated. From the available data it appears that lower populated urban areas in the Northwestern and Western United States have higher median incomes than that of the Eastern and Southern states. Figure 9 is presented only for graphical illustration of this observation.

Table 5. Population and Socio-Economic Attribute Correlation Matrix

Total Population	1.0000				
Total Dwelling Units	0.9971	1.0000			
Car Ownership	0.9954	0.9914	1.0000		
Employment	0.9940	0.9962	0.9877	1.0000	
Median Income	0.0900	0.0874	0.0758	0.1006	1.0000

Trip Purpose and Mode of Travel

In order to attempt a prediction of future trip purpose it is necessary to make some qualifying assumptions. One such assumption might reasonably be that the distribution of trips with respect to purpose in the future can be related to the distribution of trips with respect to purpose in the present. As such, the quantification of present trip purpose becomes necessary.

For an urban area there are various purposes for trips (viz., from-home, work, personal business, etc., or to-home, work, personal business, etc.) which can be displayed in a trip table matrix, plotting the trips as X_{ij} wherein i = the "from-trips" rows and j = the "to-trips" columns. With such a matrix it is possible to compute $T._j$ values of totalized "to-trips" and $T_i.$ values of totalized "from-trips". Naturally the value of T.. should equal the summation of either $T._j$ or $T_i.$ values.

In addition, it is possible to construct several matrices (e.g., Auto Driver Trips, Auto Passenger Trips, Taxi Trips, Truck Passenger Trips, Transit Trips, School Bus Trips, and All Modes Trips) to exhibit such values described earlier. Looking at one of the matrices the following questions arise:

1. What is the relationship between $T._j$ values for all j's?
2. What is the relationship between $T_i.$ values for all i's?

These same questions arise for the remaining trip purpose matrices also.

In order to discover the answer to the questions posed seven trip mode matrices for $T._j$ analyses and a like number of trip mode matrices for $T_i.$ analyses were investigated. The purpose of the investigation was to quantify interrelationships between the elements within the matrices.

There are eleven attributes possible (Home, Work, Personal Business, Recreation, School, Social, Change Travel Mode, Convenience Shopping, Goods Shopping, Serve Passenger and Total) which have been in use in the past few years. There have been additional categorizations attempted in earlier O-D studies (prior to 1961) which combined Social and Recreational purposes and both types of Shopping into two categories rather than the four in use today. In addition, "Eat a Meal" and "Medical-Dental" were classified as two categories.

In order that the input data could be as uniformly descriptive as possible, and in order to maximize the quantity of input data the eleven attributes were taken and reduced by some combination of the data. The obvious combinations which first were noted were as follows:

1.) to add, where applicable, Social and Recreational trips to agree with the Social-Recreational classification given in some of the data.

2.) to add, where applicable, Goods Shopping and Convenience Shopping to give Total Shopping to agree with that classification in some of the studies.

3.) to add, where applicable, Medical-Dental to Personal Business to agree with the totalized Personal Business categorization in some of the data.

4.) to add, where applicable, Eat-a-Meal to Social-Recreational to agree with the Social plus Recreation category defined earlier.

This resulted in reducing the eleven attributes and two groups of data into the following single group of attribute classifications:

1.) Home

2.) Work

3.) School

4.) Change Travel Mode

5.) Serve a Passenger

6.) Personal Business
(Personal Business plus Medical-Dental)

7.) Social-Recreational
(Social plus Recreational)
(Social-Recreational plus Eat-a-Meal)

8.) Shopping (Total)

9.) Total Trips

Thus, after the first round of concessions, there were nine attributes and one group of data. Because of the non-applicability of some of the data to the modes of travel involved it was deemed judicious to further reduce the number of attributes. As one concession it was possible that for various modes of trips a category called "Other" could be developed. In such a category was combined interrelated or insignificant purposes. For example, in School Bus Passenger trips it seems logical to combine Work and Personal Business together since they would actually describe what could be argued to be a related purpose. (It seems acceptable to think of work as being a personal business item when thinking of School Bus Passenger trips.) It was also decided that the placement of several insignificant contributions such as Change Travel Mode, Shopping, and Serve a Passenger into one category for School Bus Passenger trips would present no untoward problem in the interpretation of data results due to the insignificance of the trip values involved. In the Auto Passenger classification it was argued that School and Serve a Passenger classifications might be commonly related. In addition, the categorization of Change Travel Mode for Auto Passengers represents such a small portion of the total that it too could be placed in with the School and Serve a Passenger classifications into the "Other" category for Auto Passenger trips. Thus it was possible to reduce the Auto Passenger list of attributes from nine to seven. Similar arguments could be advanced for other trip purposes and modes of travel.

From- and To- Auto Driver Trips

In attempting to answer the two questions previously posed concerning the relationships between the $T._j$ values and the $T..$ value as well as between the $T_i.$ values and the $T..$ value the matrix of correlation coefficients illustrated in Tables 6 and 7 were developed.

Table 6. Correlation Coefficients for Auto Driver Trips from Various Origins

Home	1.0000						
Work	0.9997	1.0000					
Pers.Bus.	0.9730	0.9718	1.0000				
Soc.-Rec.	0.9855	0.9865	0.9465	1.0000			
Shopping	0.9930	0.9925	0.9898	0.9809	1.0000		
Others	0.9936	0.9937	0.9845	0.9838	0.9979	1.0000	
Total	0.9989	0.9987	0.9803	0.9869	0.9972	0.9975	1.0000

Table 7. Correlation Coefficients for Auto Driver Trips to Various Destinations

Home	1.0000						
Work	0.9980	1.0000					
Pers.Bus.	0.9596	0.9524	1.0000				
Soc.-Rec.	0.9393	0.9418	0.8419	1.0000			
Shopping	0.9879	0.9850	0.9547	0.9565	1.0000		
Others	0.9972	0.9782	0.9369	0.9542	0.9870	1.0000	
Total	0.9978	0.9973	0.9549	0.9549	0.9939	0.9873	1.0000

It would appear that there are strong relationships between all of the $T_{\cdot j}$ values. The same strong relationship among all of the $T_{i\cdot}$ values is likewise evidenced. In order to assess a statement made earlier that second-order relations become less attractive from the R-value standpoint the data representing Auto Driver From-trips were reduced to percentages of the total. That is to say, rather than utilizing the total number of home trips, the percentages of the total trips reflected by the from-home origin was utilized. The resulting correlation matrix shown in Table 8 was developed.

Table 8. Correlation Coefficients for Percent Auto Driver Trips from Various Origins

Home	1.0000						
Work	0.3903	1.0000					
Pers.Bus.	0.1430	0.5015	1.0000				
Soc.-Rec.	0.2802	0.1992	0.5522	1.0000			
Shopping	0.3820	0.4884	0.0492	0.2519	1.0000		
Others	0.5391	0.2027	0.0803	0.2284	0.1010	1.0000	
Total	0.2532	0.3687	0.2182	0.1563	0.0006	0.1610	1.0000

In looking at the "Total" values in Table 8 it can be argued that variations in the total number of Auto Driver trips can not be utilized to express changes in the percent of such trips from specific origins. This point has been borne out in past literature (24).

From- and To- Auto Passenger Trips

The correlation matrices illustrated in Tables 9 and 10 were developed from sixteen urban study areas' data. As in the previous case, high correlation coefficients were discovered.

Table 9. Correlation Coefficients for Auto Passenger Trips from Various Origins

Home	1.0000						
Work	0.9923	1.0000					
Pers.Bus.	0.9566	0.9470	1.0000				
Soc.-Rec.	0.9806	0.9563	0.9053	1.0000			
Shopping	0.9931	0.9792	0.9737	0.9702	1.0000		
Others	0.9793	0.9705	0.9831	0.9378	0.9802	1.0000	
Total	0.9995	0.9893	0.9631	0.9808	0.9955	0.9820	1.0000

Table 10. Correlation Coefficients for Auto Passenger Trips to Various Destinations

Home	1.0000						
Work	0.9739	1.0000					
Pers.Bus.	0.9097	0.9546	1.0000				
Soc.-Rec.	0.9423	0.8536	0.7567	1.0000			
Shopping	0.9828	0.9443	0.8986	0.9298	1.0000		
Others	0.9267	0.9307	0.9045	0.8173	0.8726	1.0000	
Total	0.9997	0.9691	0.9049	0.9494	0.9826	0.9245	1.0000

From- and To- Transit Passenger Trips

In analyzing the Transit Passenger Trip data from seventeen urban area studies the following correlation matrices shown in Tables 11 and 12 were formulated. Again, it appears that a strong relationship exists between and among the various entries.

Table 11. Correlation Coefficients for Transit Passenger Trips from Origins

Home	1.0000						
Work	0.9969	1.0000					
Pers.Bus.	0.9972	0.9980	1.0000				
Soc.-Rec.	0.9642	0.9693	0.9733	1.0000			
Shopping	0.9729	0.9801	0.9824	0.9967	1.0000		
Others	0.9532	0.9308	0.9307	0.8659	0.8733	1.0000	
Total	0.9997	0.9977	0.9977	0.9685	0.9767	0.9498	1.0000

Table 12. Correlation Coefficients for Transit Passenger Trips to Various Destinations

Home	1.0000						
Work	0.9978	1.0000					
Pers.Bus.	0.9968	0.9976	1.0000				
Soc.-Rec.	0.9631	0.9643	0.9647	1.0000			
Shopping	0.9779	0.9813	0.9817	0.9947	1.0000		
Others	0.9473	0.9284	0.9266	0.8562	0.8730	1.0000	
Total	0.9999	0.9981	0.9970	0.9665	0.9806	0.9442	1.0000

From- and To- Taxi Passenger Trips

In utilizing the data from eighteen urban area studies it was found that there exists a very definable relationship between and among taxi passenger origin trips as well as taxi passenger destination trips. The correlation coefficient matrices given in Tables 13 and 14 illustrate this.

Table 13. Correlation Coefficients for Taxi Passenger Trips from Various Origins

Home	1.0000						
Work	0.9970	1.0000					
Pers.Bus.	0.9977	0.9931	1.0000				
Soc.-Rec.	0.9904	0.9930	0.9830	1.0000			
Shopping	0.9849	0.9763	0.9681	0.9603	1.0000		
Others	0.9399	0.9413	0.9534	0.9200	0.9083	1.0000	
Total	0.9990	0.9970	0.9989	0.9883	0.9830	0.9534	1.0000

Table 14. Correlation Coefficients for Taxi Passenger Trips to Various Destinations

Home	1.0000						
Work	0.9869	1.0000					
Pers.Bus.	0.9600	0.9731	1.0000				
Soc.-Rec.	0.9938	0.9721	0.9352	1.0000			
Shopping	0.9557	0.9698	0.9939	0.9283	1.0000		
Others	0.9622	0.9279	0.9008	0.9602	0.8947	1.0000	
Total	0.9989	0.9914	0.9706	0.9907	0.9667	0.9574	1.0000

From- and To- Truck Passenger Trips

Some of the weakest correlations in this study were found during the course of this investigation into truck passenger trips. Fortunately, the magnitude of such trips is generally of such a slight nature as to be of little or no concern to the transportation planner. An obvious exception to this generalized statement is the truck passenger trip which occurs during the part of the day which reflects the greatest vehicular travel, the peak hour. The important trip is the truck driver trip, not the truck passenger trip. The truck driver trip is taken into account in the "All Modes" trips which combine all of the vehicles into one category.

The correlation coefficients exhibited in Table 15 relate to origins while those in Table 16 relate to destinations.

Table 15. Correlation Coefficients for Truck Passenger Trips from Various Origins

Home	1.0000						
Work	0.8632	1.0000					
Pers.Bus.	0.8596	0.7337	1.0000				
Soc.-Rec.	0.6817	0.4901	0.3522	1.0000			
Shopping	0.8677	0.7039	0.7137	0.7365	1.0000		
Others	0.8557	0.6852	0.8055	0.5912	0.7341	1.0000	
Total	0.9741	0.9439	0.8261	0.6784	0.8552	0.8298	1.0000

Table 16. Correlation Coefficients for Truck Passenger Trips to Various Destinations

Home	1.0000						
Work	0.7516	1.0000					
Pers.Bus.	0.5563	0.3109	1.0000				
Soc.-Rec.	0.8260	0.4874	0.3895	1.0000			
Shopping	0.8437	0.5803	0.6690	0.7238	1.0000		
Others	0.8653	0.6795	0.6372	0.5774	0.7476	1.0000	
Total	0.9565	0.8979	0.5313	0.7701	0.8189	0.8456	1.0000

From- and To- School Bus Passenger Trips

As shown in Table 17, the correlation of from-home school bus passenger trips to total from- trips by school bus passengers is given as 1.0000. This is due to rounding off the value of the correlation coefficient beyond the fourth place after the decimal. The correlations given in Tables 17 and 18 illustrate origin and destination relationships among the purposes listed.

Table 17. Correlation Coefficients for School Bus Passenger Trips from Various Origins

Home	1.0000					
Wk-P.Bus.	0.9089	1.0000				
Soc.-Rec.	0.9254	0.8890	1.0000			
School	0.9998	0.9038	0.9251	1.0000		
Others	0.8821	0.8884	0.8747	0.8837	1.0000	
Total	1.0000	0.9087	0.9269	0.9999	0.8855	1.0000

Table 18. Correlation Coefficients for School Bus Passenger Trips to Various Destinations

Home	1.0000					
Wk-P.Bus.	0.1457	1.0000				
Soc.-Rec.	0.8055	0.3697	1.0000			
School	0.9995	0.1278	0.8099	1.0000		
Others	0.7638	0.7089	0.7460	0.7519	1.0000	
Total	0.9999	0.1523	0.8100	0.9996	0.7677	1.0000

From- and To- Trips by All Modes

Even more important to the transportation planner than Auto Driver Trips is the totalization of all modes trips in an urban area. The correlation coefficients presented in Table 19 and in Table 20 represent the interrelationships which exist between and among all of the purposes for all modes of vehicular travel within the urban area. This categorization, more than any other, is a true representation of the propensity toward vehicular travel. Travel desires can be satisfied by many and varied forms of transportation. In the future we can not be certain of the form of transportation, but we can be certain that the desire to travel will most definitly exist.

Table 19. Correlation Coefficients for All Modes from Various Origins

Home	1.0000						
Work	0.9995	1.0000					
Pers.Bus.	0.9731	0.9690	1.0000				
Soc.-Rec.	0.9802	0.9798	0.9361	1.0000			
Shopping	0.9939	0.9915	0.9881	0.9774	1.0000		
Others	0.9721	0.9681	0.9960	0.9397	0.9859	1.0000	
Total	0.9984	0.9971	0.9827	0.9799	0.9982	0.9824	1.0000

Table 20. Correlation Coefficients for All Modes to Various Destinations

Home	1.0000						
Work	0.9980	1.0000					
Pers.Bus.	0.9665	0.9615	1.0000				
Soc.-Rec.	0.9335	0.9269	0.8444	1.0000			
Shopping	0.9903	0.9845	0.9550	0.9587	1.0000		
Others	0.9783	0.9735	0.9587	0.9017	0.9621	1.0000	
Total	0.9988	0.9963	0.9618	0.9470	0.9937	0.9800	1.0000

Population Influences

It had been found earlier that population, dwelling units, car ownership and employment were highly correlated. Each of these attributes might be categorized as being a measure of "size" of the urban area in question. It seems quite attractive on an intuitive basis to expect that trip production and purpose should be related to the size factor described above. Choosing population values as being one good representation of the size factor, the correlation coefficients illustrated in Table 21 and Table 22 were determined from the data.

Table 21. Correlation Coefficients Between Population and the Mode-Purpose Listed for Trips from Origins

	Origins						
	Home	Work	Pers Bus.	Soc. Rec.	Shop	Other	Total
Auto Driver	.9898	.9933	.8783	.9198	.9556	.9589	.9851
Passengers							
Auto	.9818	.9862	.7824	.9465	.9427	.7735	.9806
Transit	.9831	.9741	.9729	.9093	.9251	.9799	.9813
Taxi	.9913	.9903	.9911	.9917	.9665	.9480	.9929
Truck	.8157	.7650	.8640	.2384	.3514	.5917	.6132
School Bus*	.9672	.8395		.9409	.8541		.9679
All Modes	.9919	.9946	.8875	.9429	.9653	.9536	.9891

* The correlation between School Bus Passenger from- trips and population was found to be 0.9687 with School as the origin

Table 22. Correlation Coefficients Between Population and the Mode-Purpose Listed for Trips to Destinations

	Destinations						
	Home	Work	Pers Bus.	Soc. Rec.	Shop	Other	Total
Auto Driver	.9893	.9948	.8724	.9201	.9552	.9579	.9851
Passengers							
Auto	.9812	.9854	.7797	.9339	.9361	.7869	.9806
Transit	.9832	.9763	.9745	.9072	.9313	.9762	.9813
Taxi	.9766	.9382	.9137	.9862	.9048	.9552	.9709
Truck	.5609	.4578	.4039	.1977	.3416	.6162	.5119
School Bus*	.8652	.0475		.8985	.5733		.8688
All Modes	.9915	.9950	.8833	.9437	.9657	.9492	.9889

In studying the correlation coefficients given in Tables 21 and 22 indications are that population changes have seemingly little explained effect on respective changes in truck passenger trips. This analogy could also be applied to certain categorizations of school bus passenger trips. Generally, the magnitude of truck passenger trips

* The correlation between School Bus Passenger to- trips with School as a destination and population was found to be equal to 0.8711.

as a whole and school bus passenger trips for purposes other than school, home, or total considerations is such that the values can be disregarded on an individual basis since the total impact on the transportation system for the urban area is reflected in the "All Modes" categorization of trip purpose. Generally we would find about one truck passenger trip per two hundred or more people in an urban area with a population of from 30,000 to 800,000 on a daily basis. When categorization of the purpose of these trips is attempted the results become more and more meaningless. With respect to school bus passenger trips for origins and destinations other than school or home we might expect to find a total for all other categorizations to be approximately one to two percent of the total daily school bus passenger trips.

It was decided to neglect further analysis of Truck Passenger trips and all School Bus Passenger trips except three, those related to home, school or total trips. This was justified on the basis of insignificance of the contribution of these trips to the total number of trips experienced in the urban area. In addition, whatever effect they do have on the total trips experienced in the urban area will be included in the analysis of All-Modes trips.

In classifying the various modes of trip making with respect to importance it was argued that the All-Modes trips would be the most important, the Auto Driver trips would be the second most important and the Auto Passenger trips would be the third most important. The remaining passenger trip modes, Transit Passenger and Taxi Passenger trips would fall into fourth position or rating.

With such excellent correlations as exhibited in Table 21 and in Table 22 for the four classifications previously given it was decided to define equations of "best fit" which contained but one variable other than that being determined. After plotting all of the data versus population it appeared that a linear equation would describe the data adequately.

In order that the use of a linear equation could be justified it was necessary to compare the fit of a non-linear equation to that of the linear equation. The basis of comparison was the differences in the respective standard errors of estimate, the coefficients of determination and the F-ratios. The results of the study are outlined in Appendix B.

The equation chosen for describing the data was of the form

$$Y = a + bX$$

where Y = the attribute being estimated

X = the population estimate.

The equations of "best fit" determined by standard least squares techniques are listed in Table 23, and the graphical illustrations of these equations are presented in Figures 10 through 51 inclusive, in Appendix A.

Table 23. Macroscopic Level of Investigation
Model Summary

Model No.*	a	b	N	R	R^2	F
1.	0.017	0.60	12	0.999	0.997	4171
2.	-1.87	0.306	22	0.992	0.983	1190
3.	3.40	0.318	22	0.995	0.989	1870
4.	-2.50	0.370	22	0.986	0.973	716
5.	13.66	0.45	16	0.989	0.979	640
6.	3.61	0.308	16	0.995	0.990	1330
7.	12.23	0.054	16	0.872	0.761	45
8.	4.32	0.14	16	0.920	0.847	77
9.	9.30	0.136	16	0.955	0.912	146
10.	9.87	0.181	16	0.958	0.918	156
11.	53.0	1.268	16	0.985	0.970	460
12.	6.7	0.268	15	0.981	0.963	336
13.	-0.32	0.73	15	0.985	0.971	436
14.	4.5	0.02	15	0.780	0.608	20
15.	1.51	0.183	15	0.934	0.872	888
16.	1.55	0.065	15	0.936	0.876	92
17.	5.78	0.034	15	0.787	0.619	21
18.	21.55	0.641	15	0.981	0.962	325
19.	-8.26	0.09	15	0.983	0.964	358
20.	-5.86	0.058	15	0.976	0.951	127
21.	-0.54	0.0076	15	0.975	0.950	187
22.	-0.99	0.010	15	0.907	0.821	121
23.	-1.16	0.012	15	0.931	0.866	120
24.	-2.07	0.022	15	0.976	0.951	126
25.	-18.90	0.20	15	0.981	0.964	345
26.	-0.43	0.0073	15	0.977	0.956	79
27.	-0.12	0.0017	15	0.914	0.836	71
28.	-0.16	0.0019	15	0.986	0.973	78
29.	-0.09	0.0012	15	0.905	0.900	53
30.	-0.07	0.0008	15	0.955	0.911	28
31.	-0.80	0.015	15	0.971	0.942	52
32.	-0.85	0.027	16	0.865	0.749	42
33.	-1.10	0.028	16	0.871	0.759	44
34.	-1.73	0.056	16	0.869	0.755	43
35.	12.57	0.830	16	0.991	0.983	811
36.	-0.78	0.441	16	0.995	0.990	1400
37.	15.64	0.084	16	0.883	0.780	50
38.	5.11	0.337	16	0.944	0.891	114
39.	9.48	0.215	16	0.966	0.933	194

Table 23. Macroscopic Level of Investigation Model Summary

Model No.*	a	b	N	R	R^2	F
40.	14.9	0.25	16	0.949	0.901	127
41.	56.9	2.158	16	0.989	0.978	618
42.	14.71	0.451	16	0.990	0.980	68
43.	3.5	0.307	16	0.993	0.987	1037
44.	12.02	0.054	16	0.878	0.771	47
45.	4.1	0.14	16	0.920	0.846	77
46.	9.16	0.14	16	0.956	0.913	147
47.	9.53	0.18	16	0.959	0.919	160
48.	53.0	1.268	16	0.985	0.970	460
49.	8.28	0.271	15	0.982	0.964	348
50.	-0.17	0.074	15	0.986	0.973	463
51.	4.2	0.0199	15	0.782	0.612	20
52.	2.52	0.185	15	0.947	0.899	112
53.	1.69	0.065	15	0.943	0.889	104
54.	5.03	0.026	15	0.773	0.600	19
55.	21.6	0.641	15	0.981	0.962	325
56.	-1.09	0.028	15	0.967	0.936	218
57.	-0.87	0.028	15	0.969	0.938	228
58.	-1.95	0.057	15	0.968	0.937	223
59.	-8.44	0.090	15	0.981	0.963	341
60.	-5.78	0.057	15	0.986	0.973	123
61.	-0.59	0.0079	15	0.782	0.611	21
62.	-0.77	0.0083	15	0.946	0.894	205
63.	-1.09	0.012	15	0.943	0.890	189
64.	-2.21	0.0246	15	0.774	0.600	20
65.	-18.9	0.200	15	0.981	0.962	345
66.	-0.145	0.0056	15	0.991	0.982	77
67.	-0.063	0.0025	15	0.990	0.980	76
68.	-0.128	0.0017	15	0.991	0.982	78
69.	-0.225	0.0022	15	0.992	0.983	72
70.	-0.112	0.0017	15	0.966	0.933	62
71.	-0.132	0.0012	15	0.948	0.893	49
72.	-0.804	0.0149	15	0.993	0.984	62
73.	15.18	0.833	16	0.992	0.983	857
74.	-0.81	0.441	16	0.995	0.989	1294
75.	15.2	0.084	16	0.887	0.788	52
76.	4.6	0.339	16	0.943	0.889	112
77.	9.35	0.216	16	0.965	0.932	192
78.	14.0	0.244	16	0.954	0.909	140
79.	57.0	2.158	16	0.989	0.978	631

*See next page

*The following identification numbers serve to index the model number described in Table 23:

1.	Population greater than five years of age making trip	
2.	Total number of dwelling units	
3.	Total Car ownership	
4.	Total Employment	
5.	Auto Driver Trips -	To home
6.		To work
7.		To personal business
8.		To social-recreation
9.		To shopping
10.		To other (change travel mode, serve a passenger, school)
11.		Total to-trips
12.	Auto Passenger Trips -	To home
13.		To work
14.		To personal business
15.		To social-recreation
16.		To shopping
17.		To other (ctm, sap, school)
18.		Total to-trips
19.	Transit Passenger Trips -	To home
20.		To work
21.		To personal business
22.		To social-recreation
23.		To shopping
24.		To other (ctm, sap, school)
25.		Total to-trips
26.	Taxi Passenger Trips -	To home
27.		To personal business
28.		To social-recreation
29.		To shopping
30.		To other
31.		Total to-trips
32.	School Bus Passenger Trips -	To home
33.		To school
34.		Total to-trips
35.	All Modes Trips -	To home
36.		To work
37.		To personal business
38.		To social-recreation
39.		To shopping
40.		To other
41.		Total to-trips
42.	Auto Driver Trips -	From Home
43.		From work
44.		From personal business
45.		From social-recreation
46.		From shopping

47. From other (ctm, sap, school)
48. Total from-trips
49. Auto Passenger Trips - From home
50. From work
51. From personal business
52. From social-recreation
53. From shopping
54. From other
55. Total from-trips
56. School Bus Passenger Trips - From home
57. From school
58. Total from-trips
59. Transit Passenger Trips - From home
60. From work
61. From personal business
62. From social-recreation
63. From shopping
64. From other
65. Total from-trips
66. Taxi Passenger Trips - From home
67. From work
68. From personal business
69. From social-recreation
70. From shopping
71. From other
72. Total from-trips
73. All Modes Trips - From home
74. From work
75. From personal business
76. From social-recreation
77. From shopping
78. From other
79. Total from-trips

For the Model-Summary tabulation given in Table 23, the basic model which was developed was:

$$Y = a + bX$$

where Y = attribute described by index number (thousands)

X = population (thousands)

a = constant

b = slope of regression line

N = number of observations

R = Correlation coefficient

R^2 = Coefficient of determination

F = F-ratio from Analysis of Variance

CHAPTER VI

MICROSCOPIC INVESTIGATION

After performing the macroscopic investigation wherein each urban study area was treated as an individual unit it was decided, as discussed earlier, to change the scope of the investigation to the microscopic level, that is, to the zonal level. This level of the research encompassed two phases. In the first phase each study area was investigated on an individual basis with respect to its zonal characteristics. In the second phase the data from all zones were combined with no recognition as to its former association with a specific urban area.

Zonal Attributes Within Urban Areas

The first phase of this level of study was to attempt determination of the possibility of interrelations between attributes as measured on a zonal basis within individual study areas. The common attributes which might represent the "size factor" were reported on a zonal basis in eighteen of the study areas to be zonal population, zonal car ownership, and zonal dwelling units. In fifteen of the eighteen study areas zonal labor force was reported. The zonal attributes (car ownership, dwelling units, population, labor force) from each of the respective study areas were analyzed with respect to interrelationships. The number of zones involved in this analysis totaled approximately 2500. The smallest number of zones for any study area was approximately 40 (Lake Charles, La., and Las Vegas, Nev.), while the largest number of zones for any one study area was approximately 300 (Salt Lake City, Utah).

During the course of this study more than the four attributes listed above were studied. In some cases there were as few as six of the studies which had included zonal data on a specific attribute. Some of the attributes studied in addition to the four major ones listed above were rented dwelling units, owned dwelling units, population greater than five years of age, licensed drivers, population greater than five years making trips, cars per dwelling unit, income level, retail sales, employment and land use acreage. Due to the lack of a sufficient amount of data these attributes were not included in the final analysis of eighteen study areas. It did appear, however, that a very substantial amount of over-collection of data had occurred in the great majority of study areas.

Table 24 gives the zonal correlation coefficients computed between population and three attributes, car ownership, dwelling units and labor force.

Table 25 was developed for the zonal correlation coefficients between zonal car ownership and three attributes, zonal population (also given in Table 24), dwelling units and labor force. The need for this table becomes apparent in a short while when comparison between correlation values is made. It will be seen that zonal car ownership relates in a more satisfactory manner to zonal trip production than does zonal population.

Three equations of best-fit were developed by standard least-squares techniques of the form $Y = a + b(X)$, wherein population of a zone was utilized as the X-value. These equations are graphically illustrated in Figures 52 through 54.

Table 24. Correlation Coefficients Between Zonal Population and Three Selected Attributes

Study Area*	Zonal Attributes		
	Car Ownership	Dwelling Units	Labor Force
Rapid City	.9969	.9900	.9912
Casper	.9328	.9591	-
Sioux Falls	.9758	.9629	.9770
Lewiston-Auburn	.9324	.9508	.9589
Lake Charles	.8980	.9575	.9964
Las Vegas	.9787	.9470	-
Montgomery	.7593	.9757	-
Huntsville	.9713	.9525	.9668
Charlotte	.7999	.9823	.9844
Albuquerque	.9070	.9750	.9714
Columbia	.8578	.8252	.9236
Little Rock	.9132	.9621	.9666
Chattanooga	.8359	.9795	.9802
Knoxville	.8977	.9553	.9762
Nashville	.8253	.9597	.9730
Salt Lake City	.9741	.9374	.9449
Kansas City	.9634	.9717	.9462
St. Louis	.9180	.9886	.9820

*Listed in order of population of study area.

Table 25. Correlation Coefficients Between Zonal Car Ownership and Three Selected Attributes

	Zonal Attributes		
	Population	Dwelling Units	Labor Force
Rapid City	.9969	.9889	.9928
Casper	.9328	.9492	-
Sioux Falls	.9758	.9717	.9859
Lewiston-Auburn	.9324	.8689	.9083
Lake Charles	.8980	.8864	.8943
Las Vegas	.9787	.9673	-
Montgomery	.7593	.8037	-
Huntsville	.9713	.9310	.9602
Charlotte	.7999	.8414	.8072
Albuquerque	.9070	.9086	.9263
Columbia	.8578	.7166	.8635
Little Rock	.9132	.9228	.9322
Chattanooga	.8359	.8338	.8658
Knoxville	.8977	.8667	.8864
Nashville	.8253	.8407	.8719
Salt Lake City	.9741	.9395	.9545
Kansas City	.9634	.9349	.9174
St. Louis	.9180	.9200	.9081

Continuing the investigation on the microscopic level, trip production was investigated on a zonal basis for eleven urban areas. Each urban study area was treated as an individual entity during the first phase of this level of study. Zonal populations were compared against zonal trip purpose utilizing at-home termini trips for one case and at-non-home termini trips for a second case. In addition, zonal car ownership was compared against respective zonal trip purpose for at-home termini trips as well as for at-non-home termini trips.

Quite naturally, one would not expect the population residing within an urban study zone which contained, say, a regional shopping center and a public school, to be related to the number of at-non-home termini trips within the zone. An in-depth study of attributes related to trip attraction due to shopping centers has been reported to be underway under the direction of Dr. Natalie Sato, as reported at the 1966 HRB conference in Washington, D.C. (29). In addition, Louis Keefer's report on trip attraction is an excellent source (30) of information on the influence of major attractions such as airports, shopping centers and industrial areas with respect to trip attraction.

Thus, the direction which was taken in the course of this research was in investigating the at-home termini trips on a zonal basis.

Trip purpose was reported in nine of the eleven studies in the following at-home termini categorizations: total, work, personal business, school, convenience shopping, goods shopping, social, and recreational. In two of the studies the combined purposes of personal business and shopping were given as one unit of data while the combined purposes of social and recreational trips were given as a separate unit of data.

In order to be able to compare the two study areas' zonal characteristics with respect to the combination sets of data (personal business-shopping and social-recreational) to the remaining data, three of the remaining studies were chosen at random. From these selected studies data which represented at-home termini personal business trips were combined with the respective goods shopping and convenience shopping data into one unit, and the at-home termini social data were combined with the respective recreational data to form another unit of comparison data.

The correlation matrix for the population comparisons is given as Table 26 and 27. The correlation coefficients for the car ownership comparisons are given in Table 28 and in Table 29.

Table 26. Correlation Coefficients Between Zonal Population and Various At-Home Termini Trip Purposes

Study Area	Total	Work	Pers. Bus.	Sch.	Conv. Shop	GAF Shop	Soc.	Rec.
Rapid City	.964	.978	.838	.930	.849	.837	.941	.917
Sioux Falls	.942	.917	.811	.657	.807	.782	.862	.772
Huntsville	.942	.957	.782	.895	.851	.722	.787	.790
Albuquerque	.903	.868	.816	.777	.812	.690	.838	.782
Columbia	.825	.676	.728	.711	.759	.742	.798	.727
Little Rock	.871	.795	.820	.788	.859	.807	.799	.807
Chattanooga	.870	.967	.827	.502	.765	.661	.827	.726
Knoxville	.877	.942	.790	.656	.801	.852	.883	.770
Nashville	.847	.952	.833	.581	.677	.747	.771	.671

Table 27. Correlation Coefficients Between Zonal Population and Five At-Home Termini Trip Purposes

Study Area	Total	Work	School	Pers.-Bus. Shopping	Social-Recreation
Casper	.8890	.9439	.8021	.9371	.8979
Lewiston-Auburn	.8866	.8878	.4015	.8451	.8605
Huntsville	.9419	.9573	.8949	.9373	.9147
Columbia	.8529	.6756	.7112	.8723	.8522
Little Rock	.8710	.7947	.7881	.9380	.8432

Table 28. Correlation Coefficients Between Zonal Car Ownership and Various At-Home Termini Trip Purposes

Study Area	Total	Work	Pers. Bus.	Sch.	Conv. Shop	GAF Shop	Soc.	Rec.
Rapid City	.967	.981	.838	.922	.851	.842	.947	.922
Sioux Falls	.958	.913	.851	.712	.902	.852	.910	.890
Huntsville	.965	.958	.790	.915	.860	.792	.805	.882
Albuquerque	.955	.936	.899	.748	.887	.775	.814	.812
Columbia	.886	.909	.433	.795	.902	.759	.831	.848
Little Rock	.953	.937	.688	.884	.953	.861	.858	.913
Chattanooga	.946	.897	.843	.695	.874	.784	.887	.771
Knoxville	.951	.912	.846	.836	.888	.837	.924	.868
Nashville	.976	.885	.880	.748	.916	.868	.941	.858

Table 29. Correlation Coefficients Between Zonal Car Ownership and Five At-Home Termini Trip Purposes

Study Area	Total	Work	School	Pers.-Bus. Shopping	Social-Recreation
Casper	.9760	.9431	.8397	.9572	.9267
Lewiston-Auburn	.9014	.9392	.5046	.8838	.9101
Huntsville	.9650	.9580	.9146	.9729	.9593
Columbia	.8858	.9089	.7945	.8197	.9328
Little Rock	.9532	.9372	.8835	.9375	.9127

It can be seen that there is an apparent difference in the correlation coefficients derived for the various at-home termini trip purposes as related to zonal population and zonal car ownership attributes. The correlation coefficients between zonal car ownership data and the various trip purposes are consistently higher than the respective zonal population correlation coefficients. The explanation for this probably lies in the hypothesis that the car ownership data reflects not only the population influence but, to some extent, reflects an economic factor as well; that is, the capability of car ownership infers travel ability.

Utilizing zonal car ownership data as the x-value input data, the equations graphically illustrated in Figures 55 through 63 were developed using least squares techniques. They represent the second and final phase of the microscopic level of investigation. The data illustrated in Figures 55 through 63 are based on a conglomeration of all available zonal data. The minimum number of zones utilized was 700 (these represented five urban areas in an analysis of a social-recreational zonal trip production relationship with zonal car ownership). Approximately 1160 zones were utilized from nine urban areas to develop zonal trip production relationships between car ownership and five separate attributes (personal business, social, recreation, convenience shopping, and goods shopping). There were eleven urban study areas' zonal data utilized to develop a zonal trip production relationship between car ownership and three attributes, namely, work, school, and total trips.

There were in excess of 1450 zones represented in this final analysis.

CHAPTER VII

CONCLUSIONS

On an urban basis it is possible to estimate the quantity of dwelling units, car ownership, employment and labor force using population as the estimator. It is also possible, within the population range of 50,000 to 800,000 to estimate the To- and From- trip purpose volumes for various modes of travel such as Auto Driver, Auto Passenger, Taxi, Transit, or Totalized All-Modes Travel, with a linear equation.

On a zonal basis it is possible to estimate various attributes associated with the zone such as car ownership, labor force or dwelling units utilizing population as the estimator. Zonal car ownership is a slightly better estimator of trip volumes when trip purpose is in question than is zonal population. By use of a set of linear equations, utilizing car ownership as the estimator, it is possible to quantify at-home termini trip volumes for various purposes.

Current origin-destination studies reflect a great amount of overcollection of data when data is used for purposes such as this thesis. Greater advantage can be taken of the manpower, money and time spent in such studies by a reevaluation of data collection procedures.

CHAPTER VIII

SUGGESTIONS FOR FUTURE RESEARCH

Based on the findings that overcollection of data (or collection of the same data under various forms) may be evident, it would seem that an identification of additional socio-economic attributes which are not strongly related, for use in developing additional trip production equations would be most sorely needed. Such identification should be made on two levels, a macroscopic or urban level and a microscopic or zonal level.

The definition of what does, and what does not, constitute the Central Business District area is quite vague in most studies. Existing guide lines for determination of characteristics to describe such an area in a suspected CBD area should be utilized.

Trip purpose with respect to categorization should be improved. For example, the categorization of personal business trips appears to be the most variable. This may be due to a difficulty in describing the attributes of a personal business trip. A clear set of guide lines for determining standard definitions for all trip purposes would be most helpful.

The method of collecting data to determine trip origins, travel routes and subsequent trip destinations by means of a roadside interview should be changed to reflect sophistication in data collection techniques. In areas where auto inspections are mandatory such a change is most assuredly possible. The results of such a change would be a lessening in the cost of an O-D study along with a continuous program of O-D sampling at the discretion of the traffic planning engineer.

APPENDICES

APPENDIX A

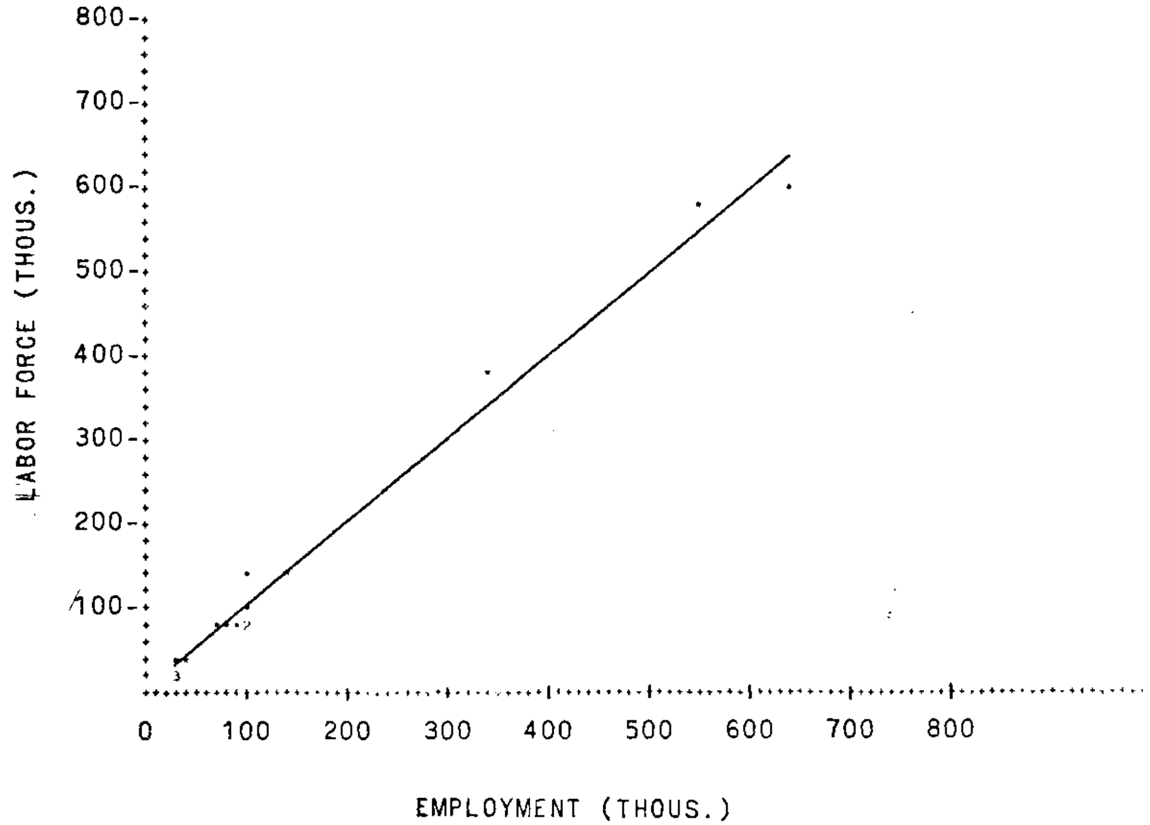
Presented hereinafter are Figures 4 through 63. Since the figures were plotted using a high speed computer, it was necessary to "code" the data locations to indicate the number of pieces of data located at any discrete position. For Figures 4 through 51 this coding is rather straight forward. A "*" indicates one piece of data, "2" indicates two pieces of data, "3" indicates three pieces of data, and so forth. No location had more than nine pieces of data.

In Figures 52 through 63, where large numbers of data might be located at a single position it was necessary to use the following coding shown in Table 32.

Table 32. Coding Utilized in Figures 52 Through 63

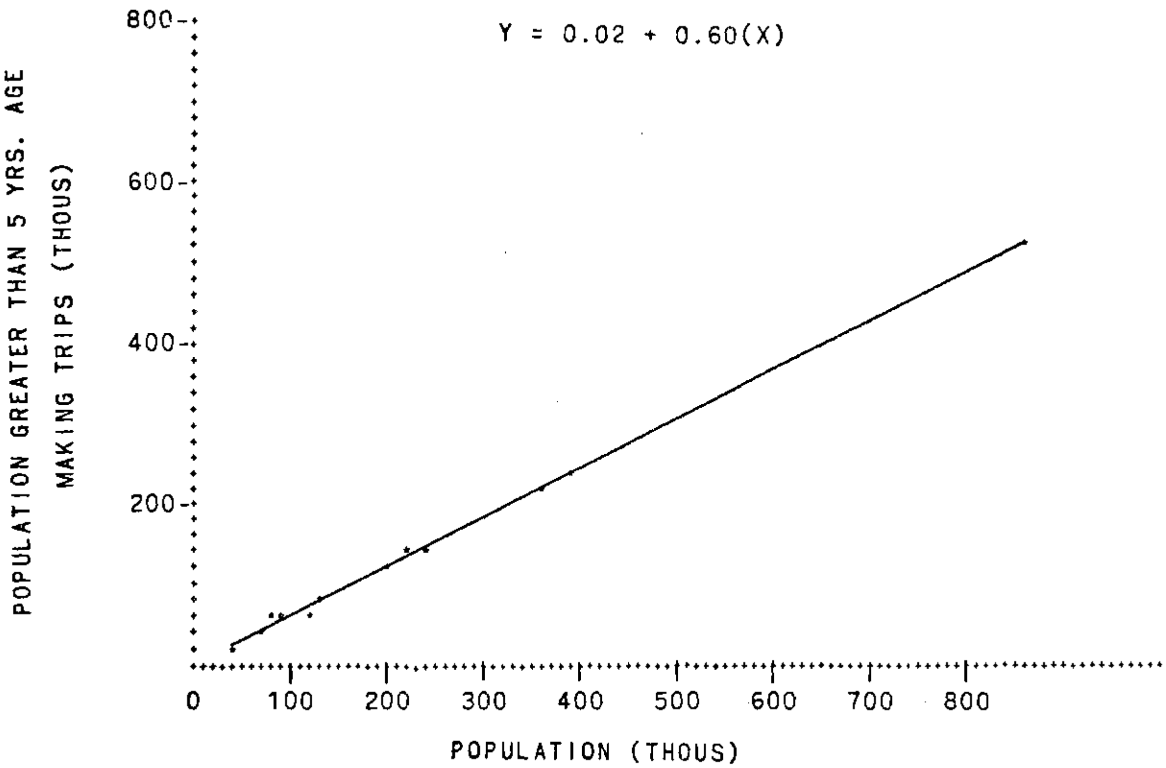
Code	Number of Observations at Specified Locations
*	1
+	2-9
1	10-19
2	20-29
3	30-39
4	40-49
5	50-59
6	60-69
7	70-79
8	80-89
9	90-99
x	100-125
#	126-149
0	150 or greater

$$Y = -0.56 + 0.991(X)$$



Correlation Coefficient (R)...........	0.992
Coefficient of Determination (R^2).....	0.985
Standard Error of Estimate............	23.9
F-ratio..............................	917

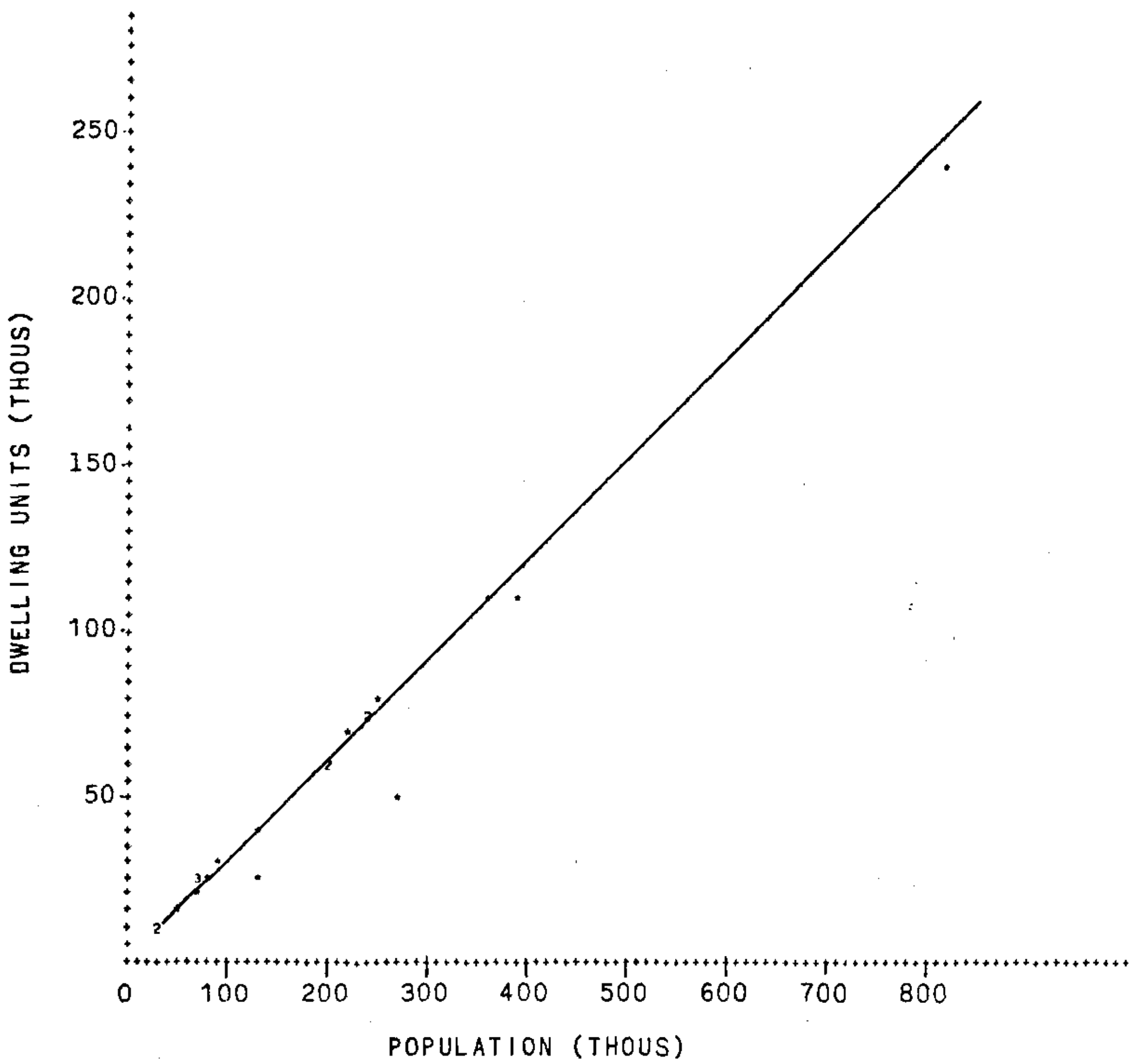
Figure 4. Labor Force - Employment



Correlation Coefficient (R)...........	0.999
Coefficient of Determination (R^2).....	0.997
Standard Error of Estimate............	6.96
F-ratio..............................	4170

Figure 5. Population Relationships

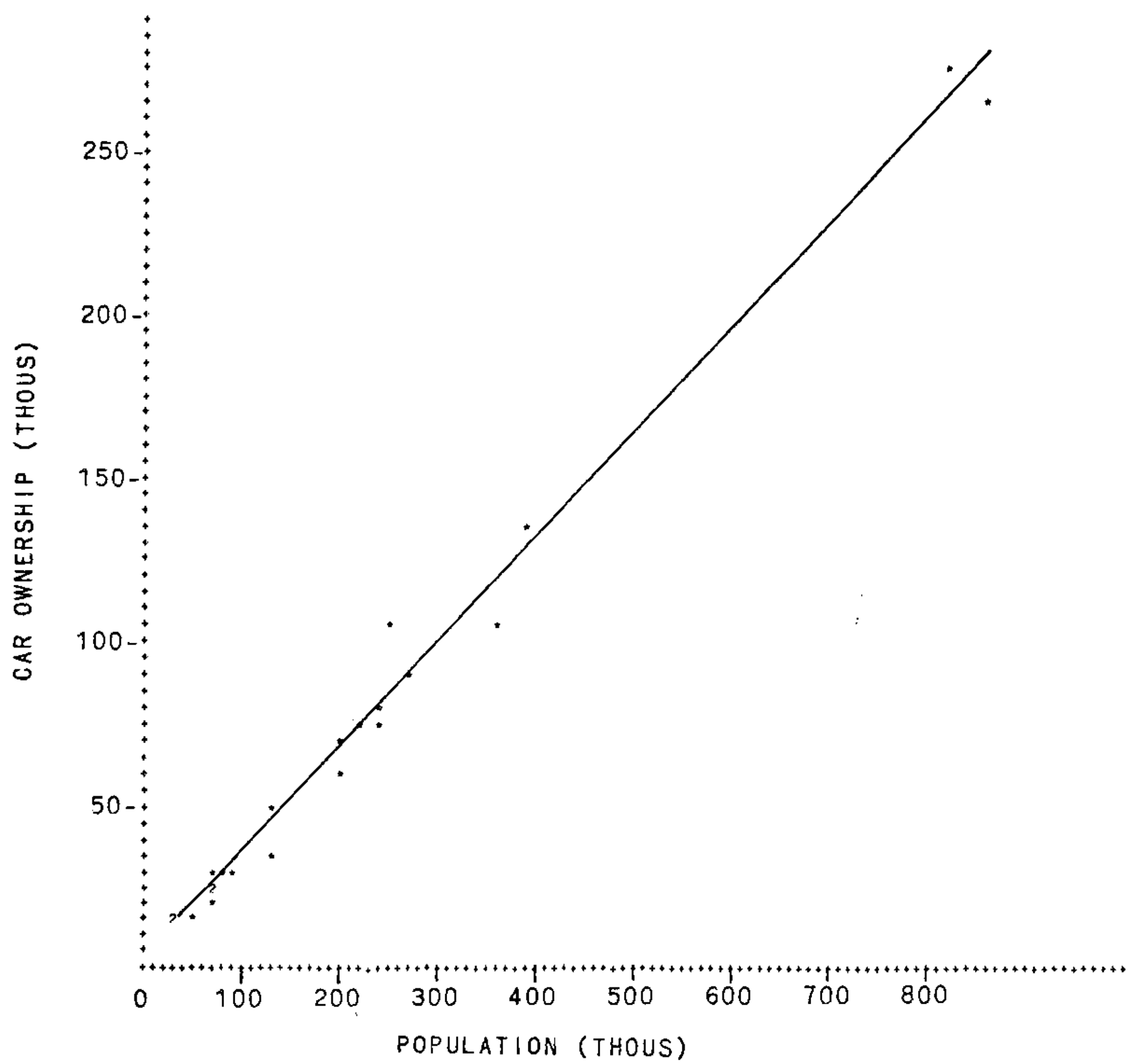
$$Y = -1.87 + 0.306(X)$$



Correlation Coefficient (R)...........	0.992
Coefficient of Determination (R^2).....	0.983
Standard Error of Estimate............	9.13
F-ratio.............................	1190

Figure 6. Dwelling Units

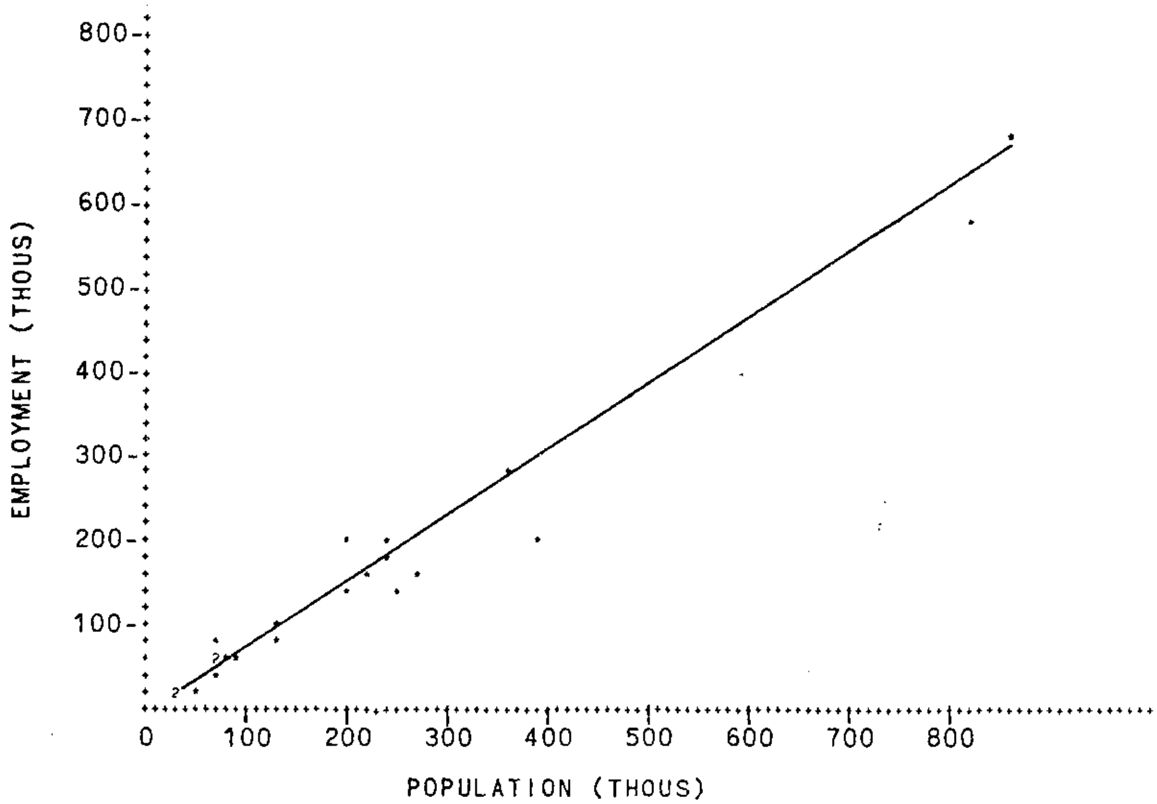
Y = 3.40 + 0.318(X)



Correlation Coefficient (R)...........	0.995
Coefficient of Determination (R^2).....	0.989
Standard Error of Estimate............	7.56
F-ratio...............................	1870

Figure 7. Car Ownership

$$Y = -2.50 + 0.370(X)$$



Correlation Coefficient (R)...........	0.986
Coefficient of Determination (R^2).....	0.973
Standard Error of Estimate...........	14.2
F-ratio.............................	716

Figure 8. Employment

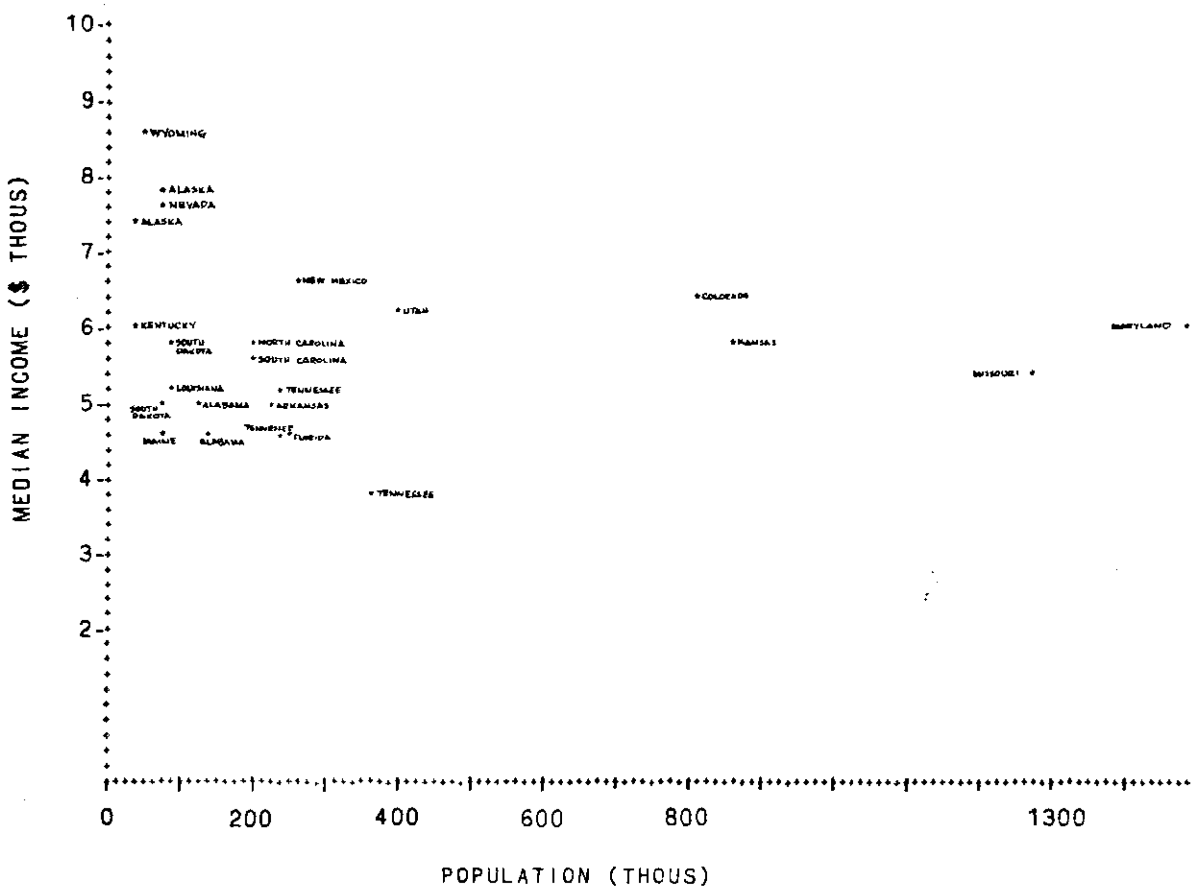
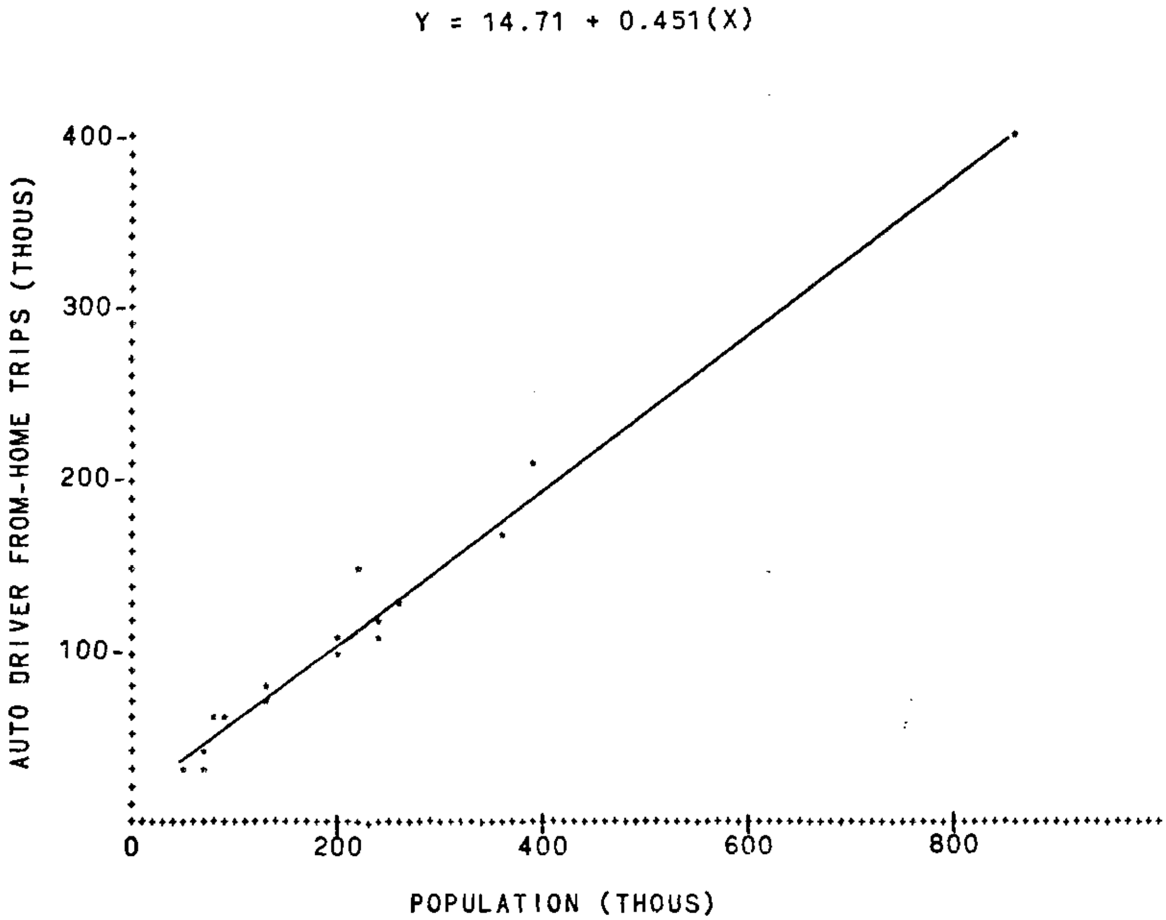
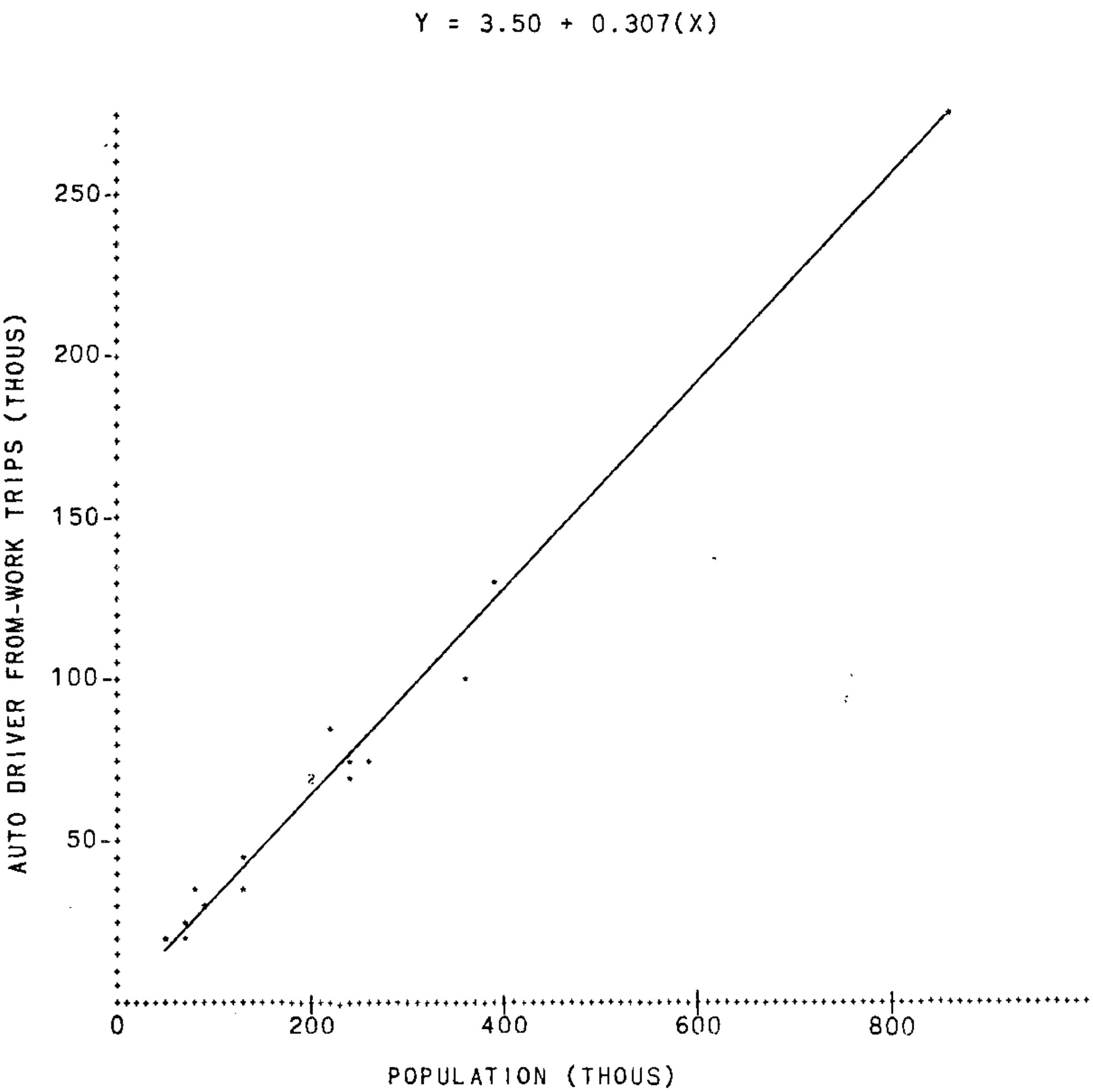


Figure 9. Median Income



Correlation Coefficient (R)........... 0.990
Coefficient of Determination (R^2)..... 0.980
Standard Error of Estimate............ 13.25
F-ratio............................. 68

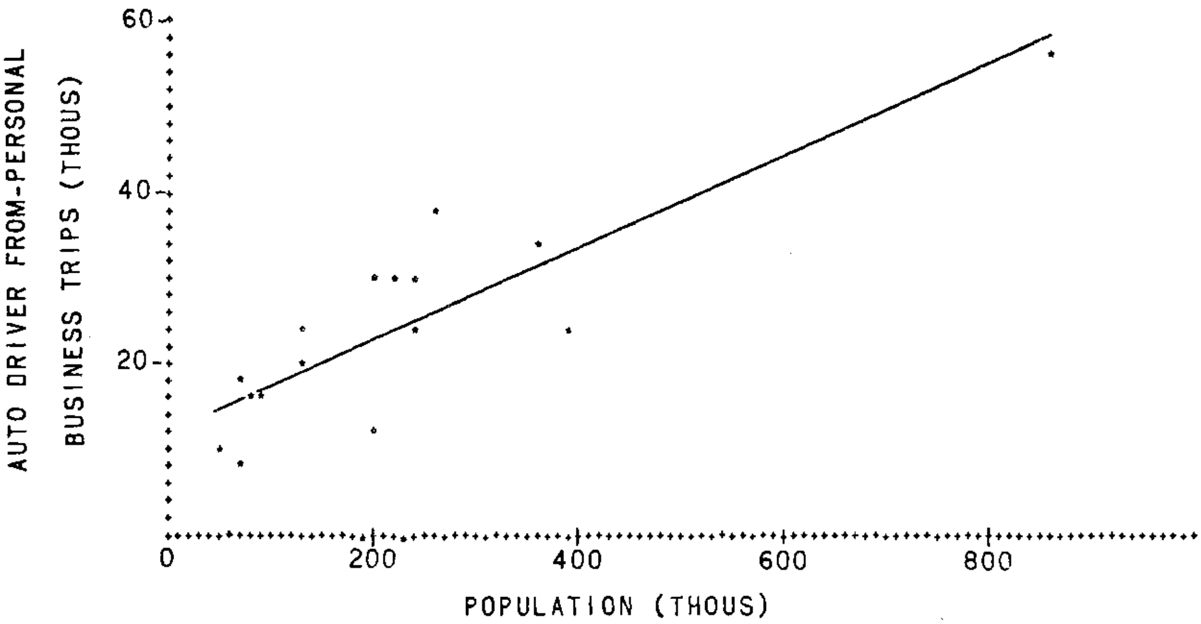
Figure 10. Auto Driver From-home Trips



Correlation Coefficient (R)........... 0.993
Coefficient of Determination (R^2)..... 0.987
Standard Error of Estimate........... 7.28
F-ratio............................ 1037

Figure 11. Auto Driver From-work Trips

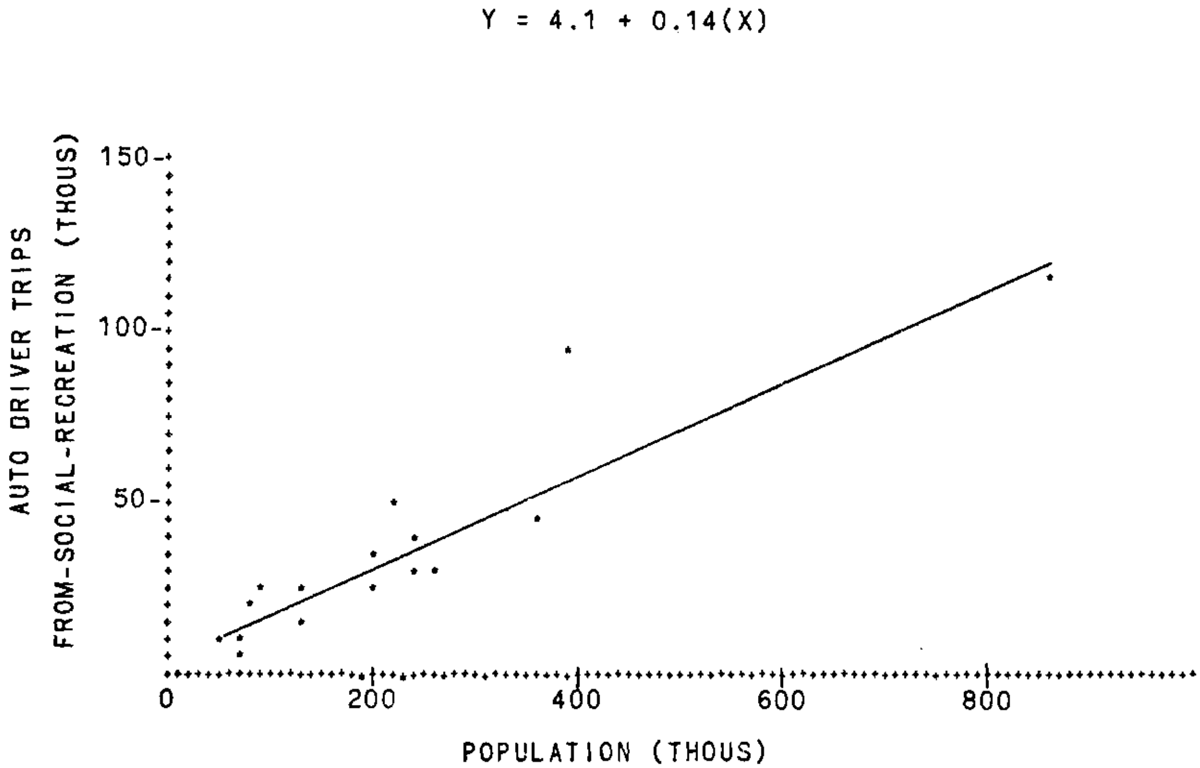
$$Y = 12.02 + 0.054(X)$$



Correlation Coefficient (R)........... 0.878
Coefficient of Determination (R^2)..... 0.771
Standard Error of Estimate............ 5.99
F-ratio.............................. 47

Figure 12.

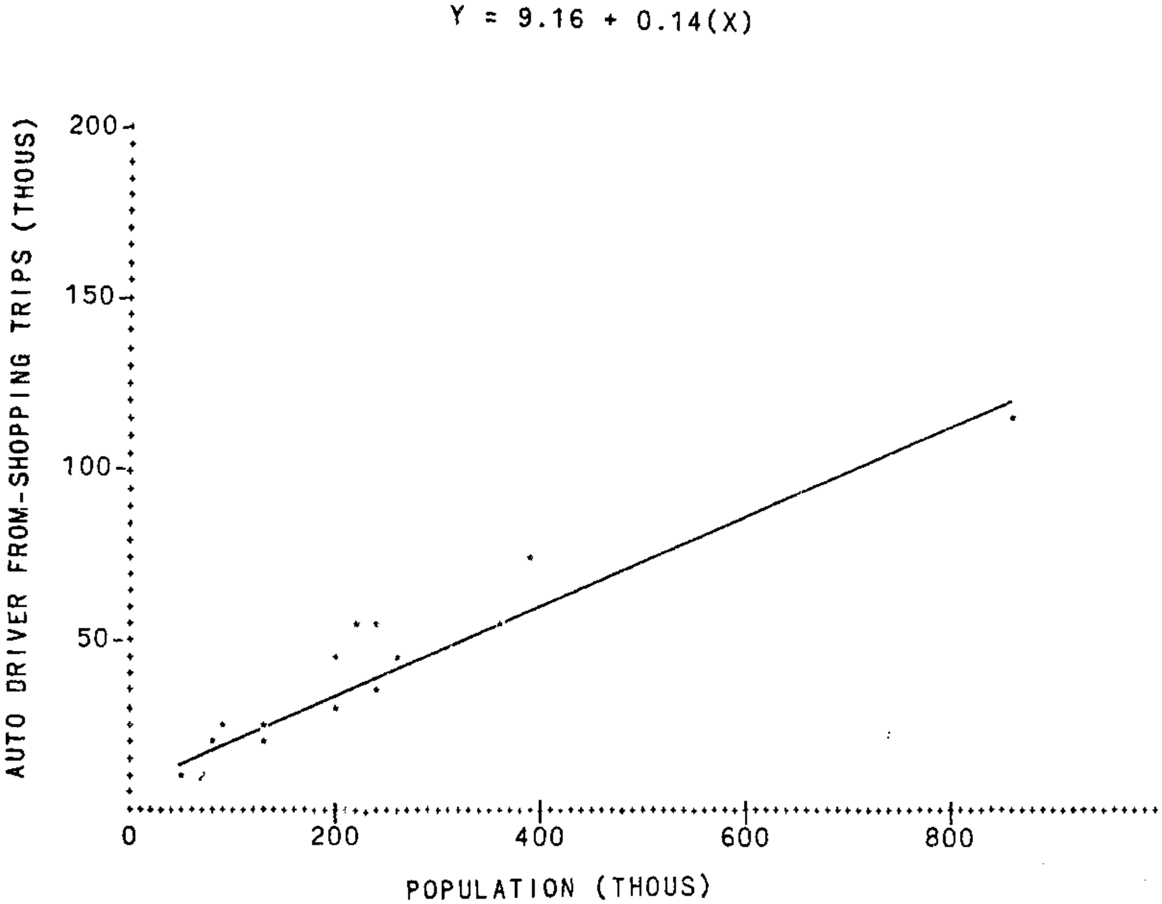
Auto Driver From-personal business Trips



Correlation Coefficient (R)	0.920
Coefficient of Determination (R^2)	0.846
Standard Error of Estimate	12.2
F-ratio	77

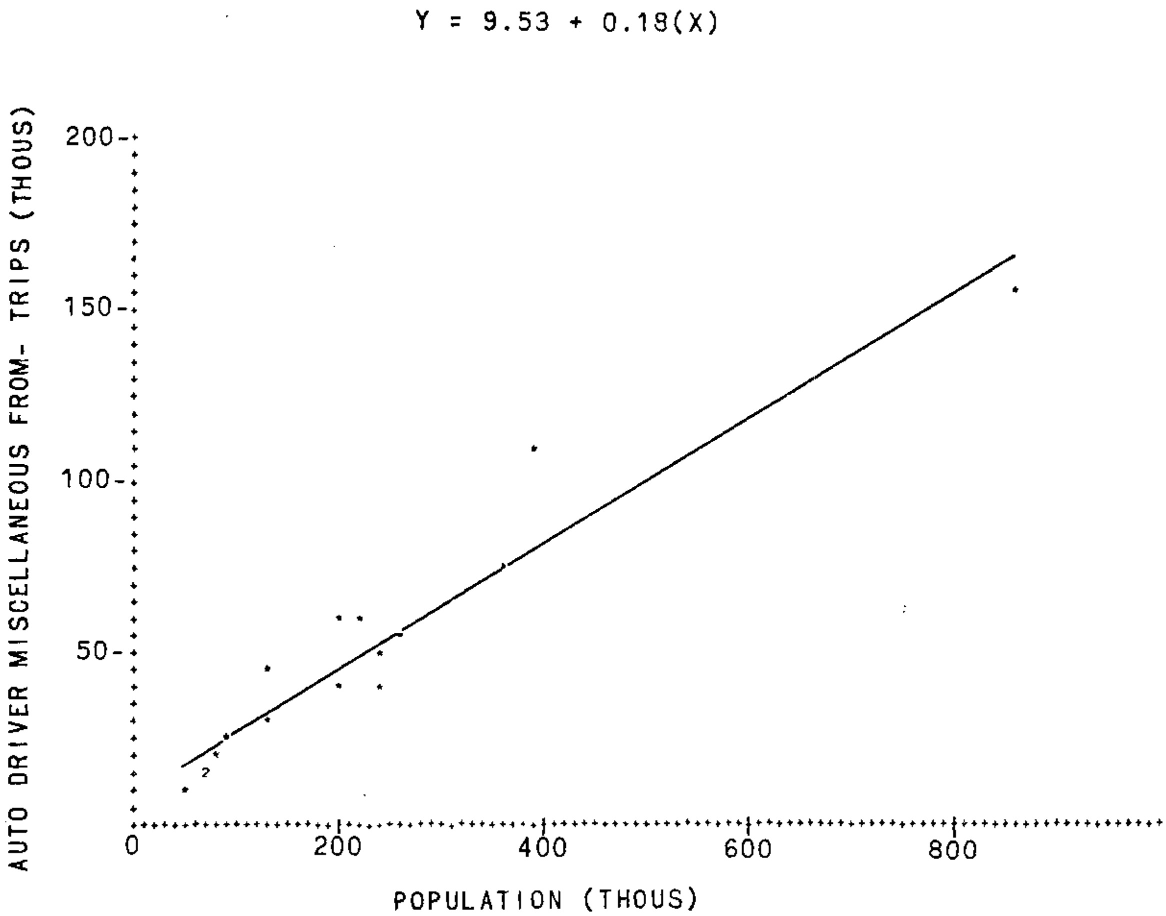
Figure 13.

Auto Driver From-social-recreation Trips



Correlation Coefficient (R)...........	0.956
Coefficient of Determination (R^2).....	0.913
Standard Error of Estimate............	8.57
F-ratio...............................	147

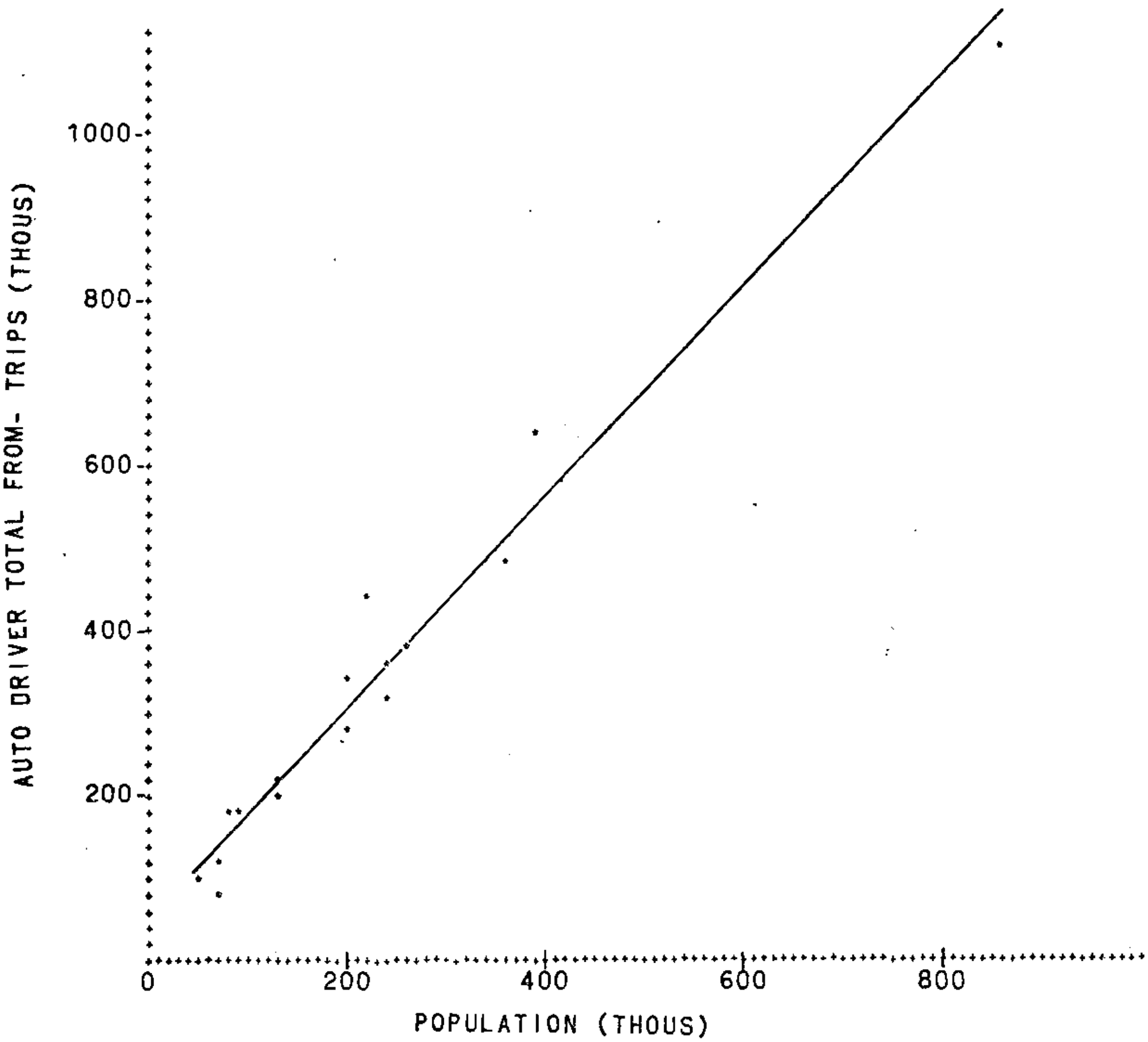
Figure 14. Auto Driver From-shopping Trips



Correlation Coefficient (R)........... 0.959
Coefficient of Determination (R^2)..... 0.919
Standard Error of Estimate............ 10.9
F-ratio............................. 160

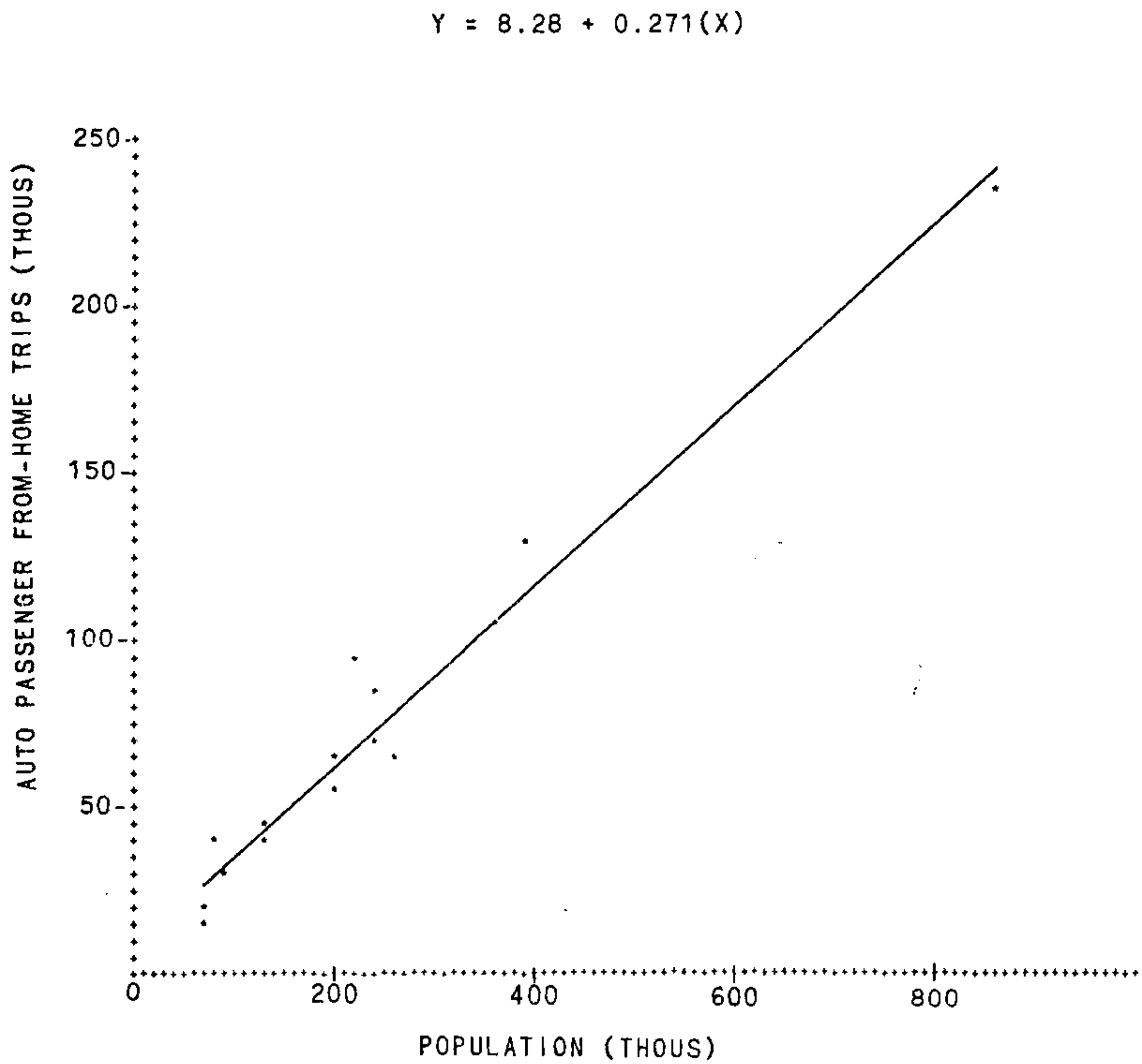
Figure 15. Auto Driver Miscellaneous From-Trips

$$Y = 53.0 + 1.268(X)$$



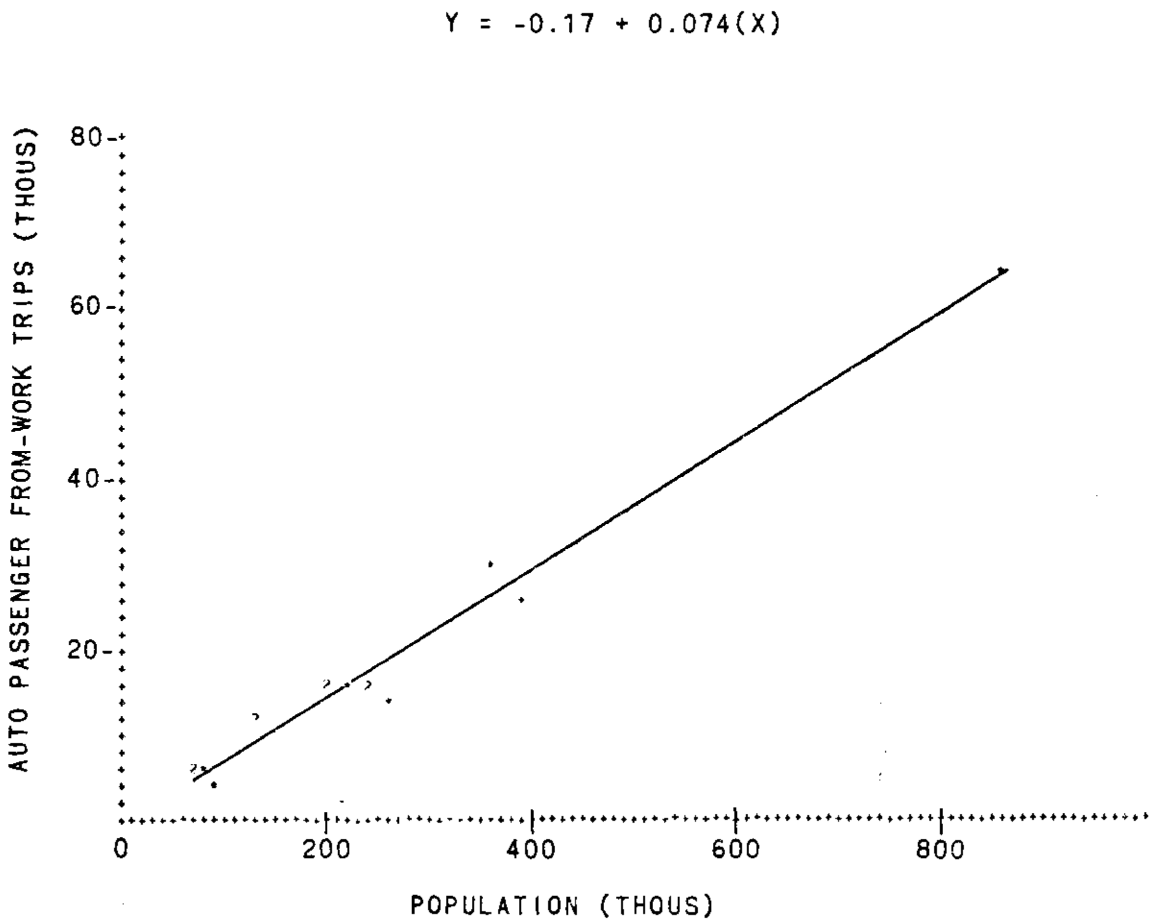
Correlation Coefficient (R)	0.985
Coefficient of Determination (R^2)	0.970
Standard Error of Estimate	45.2
F-ratio	460

Figure 16. Auto Driver Total From- Trips



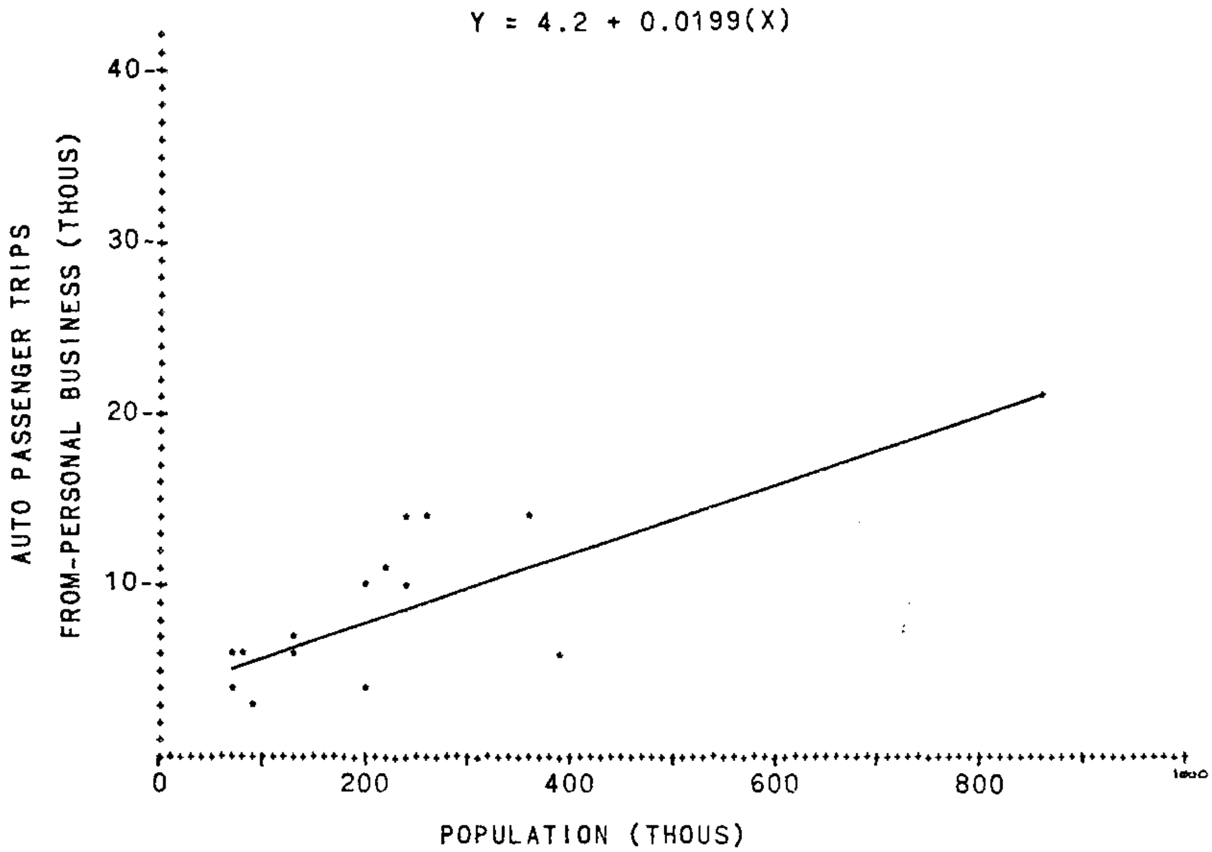
Correlation Coefficient (R)	0.982
Coefficient of Determination (R^2)	0.964
Standard Error of Estimate	10.8
F-ratio	348

Figure 17. Auto Passenger From-home Trips



Correlation Coefficient (R)...........	0.986
Coefficient of Determination (R^2).....	0.973
Standard Error of Estimate............	2.54
F-ratio.............................	463

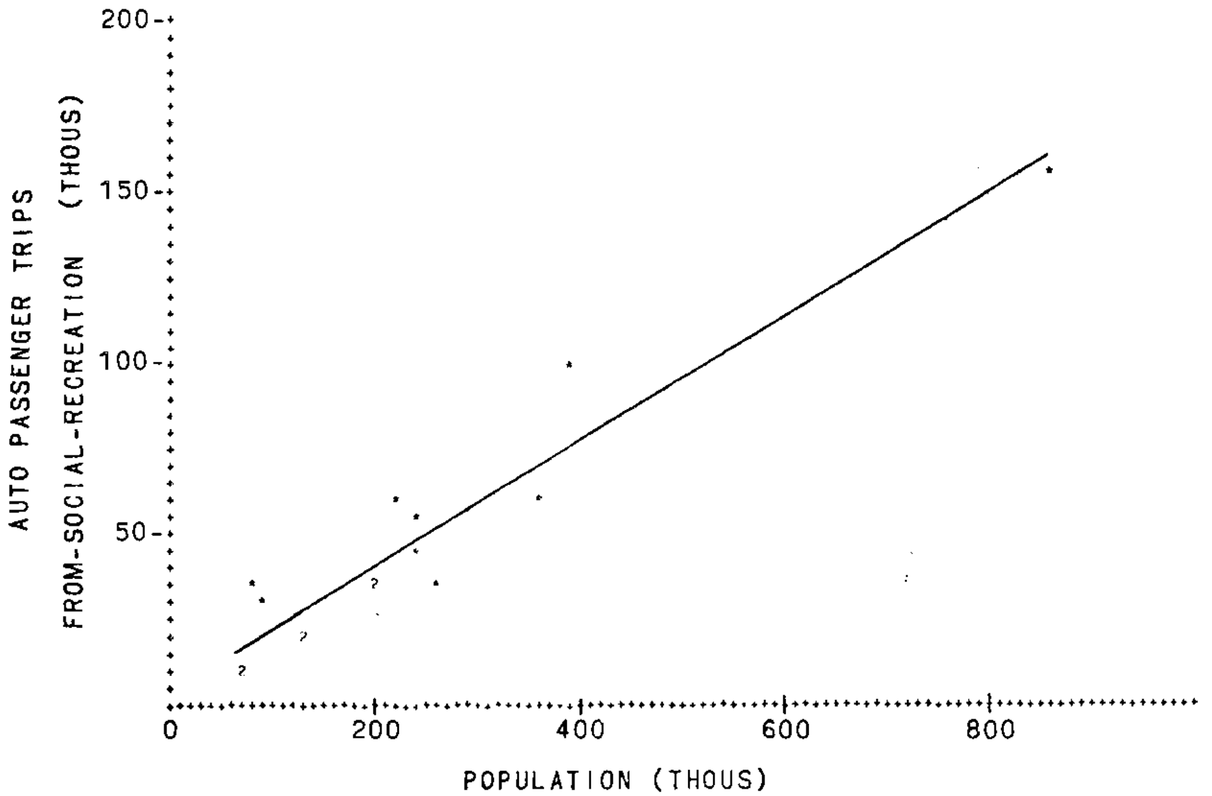
Figure 18. Auto Passenger From-work Trips



Correlation Coefficient (R)	0.782
Coefficient of Determination (R^2)	0.612
Standard Error of Estimate	3.25
F-ratio	20

Figure 19. Auto Passenger From-personal business Trips

$Y = 2.52 + 0.185(X)$

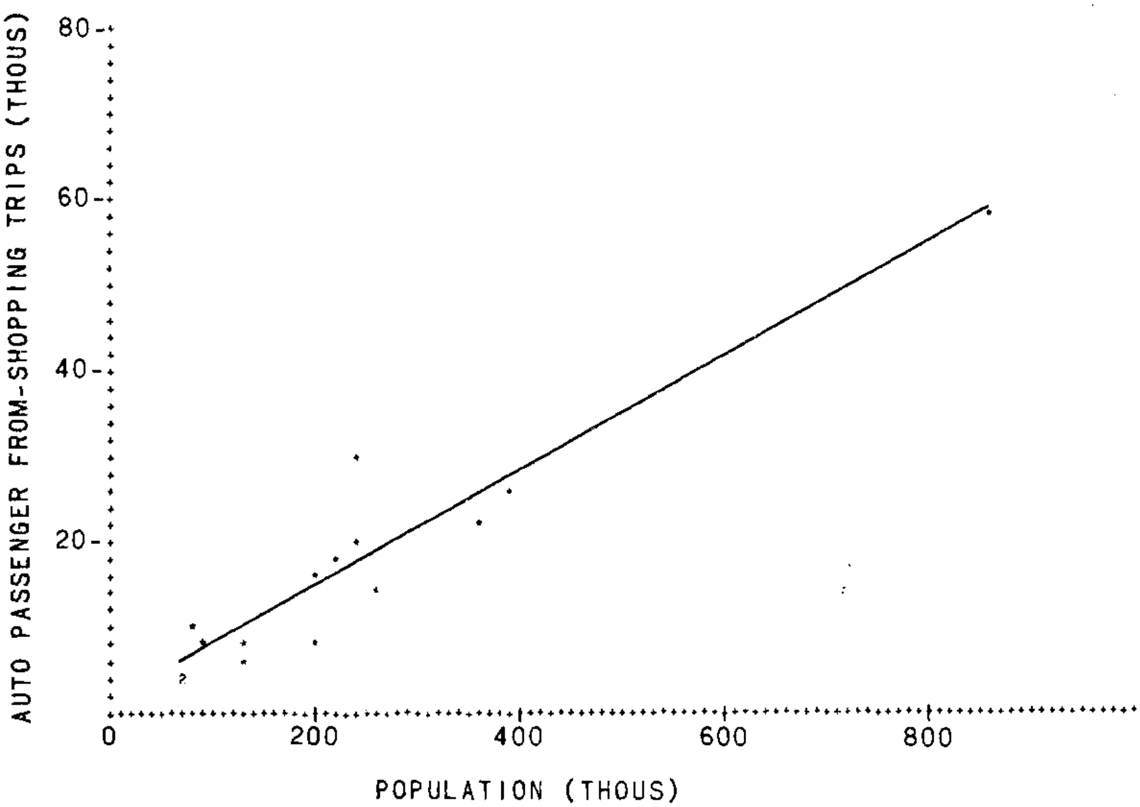


Correlation Coefficient (R)........... 0.947
Coefficient of Determination (R^2)..... 0.900
Standard Error of Estimate............ 12.9
F-ratio............................... 112

Figure 20.

Auto Passenger From-social-recreation Trips

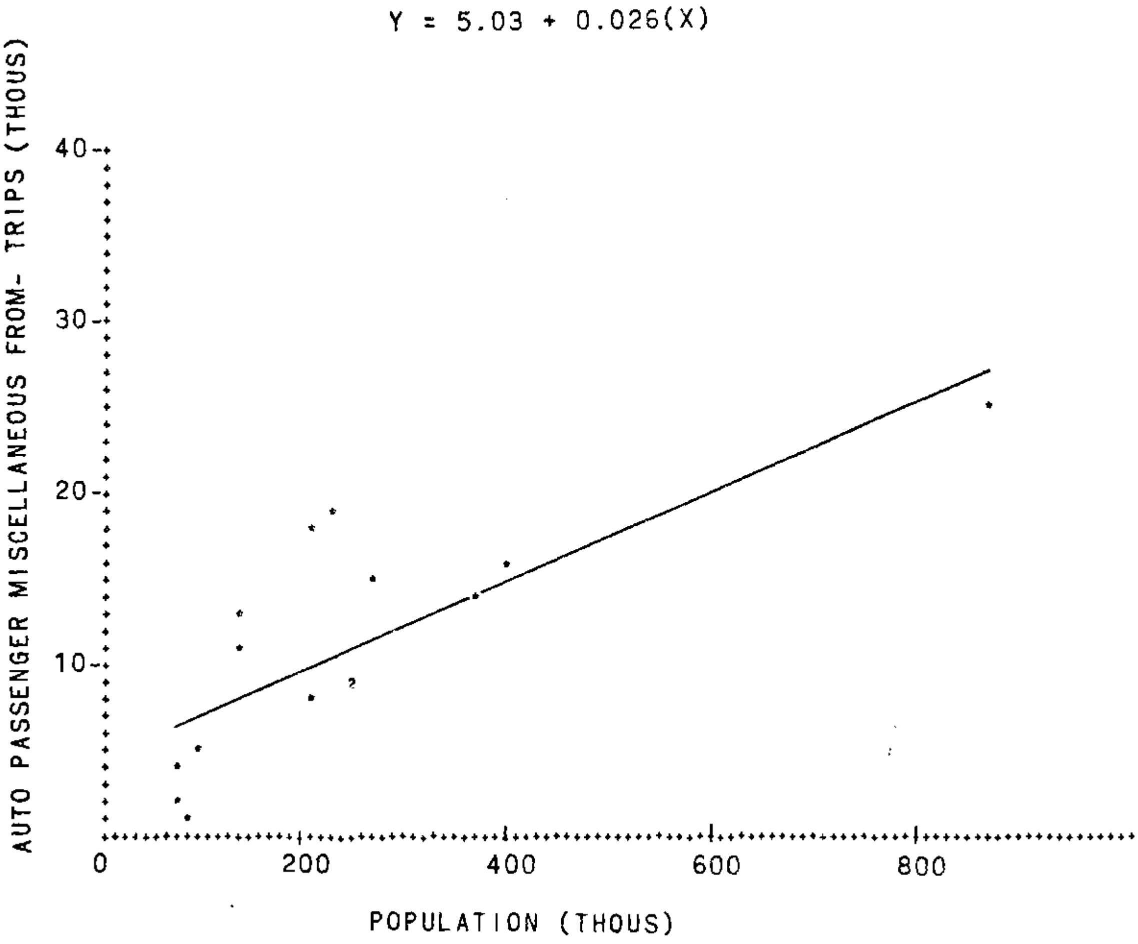
$Y = 1.69 + 0.065(X)$



Correlation Coefficient (R)...........	0.943
Coefficient of Determination (R^2).....	0.889
Standard Error of Estimate............	4.75
F-ratio...............................	104

Figure 21.

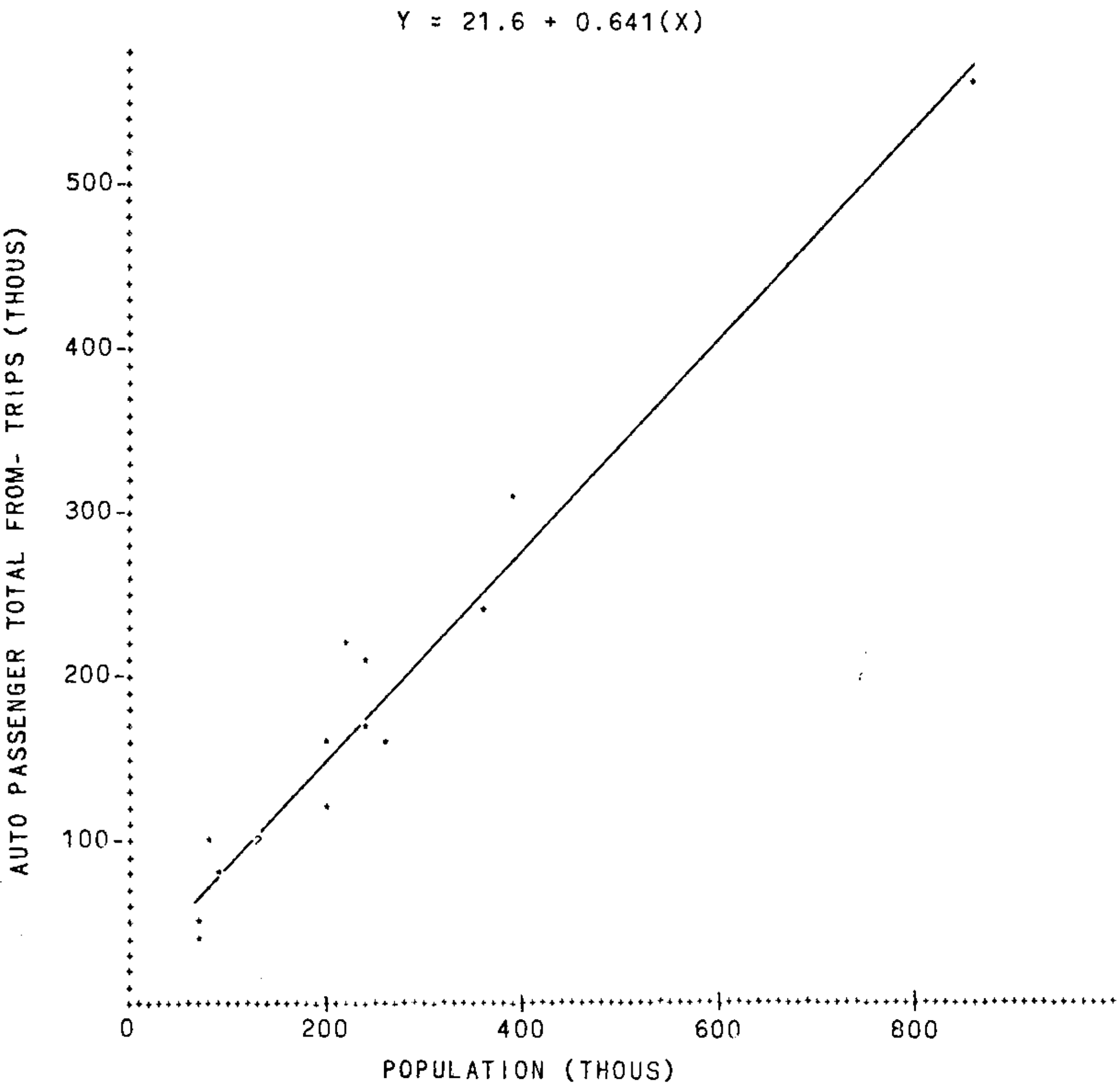
Auto Passenger From-shopping Trips



Correlation Coefficient (R)........... 0.773
Coefficient of Determination (R^2)..... 0.598
Standard Error of Estimate............ 4.39
F-ratio............................... 19

Figure 22.

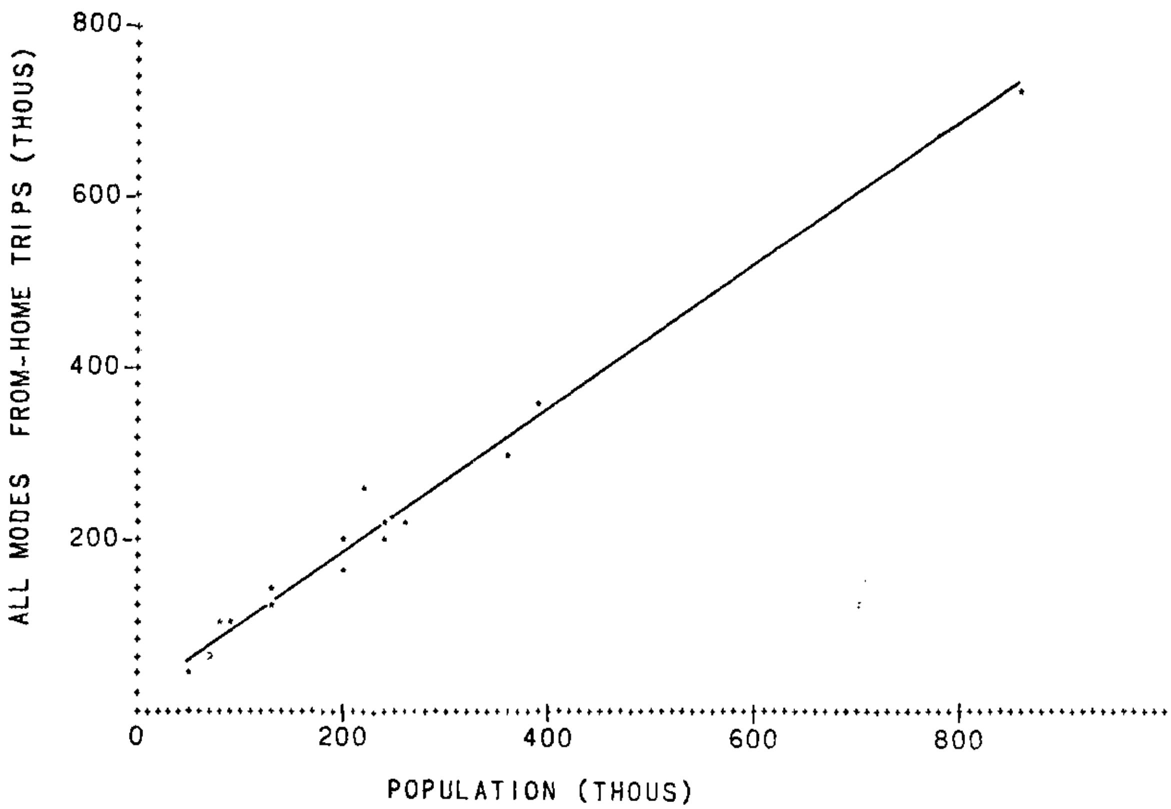
Auto Passenger Miscellaneous From- Trips



Correlation Coefficient (R)..........0.981
Coefficient of Determination (R^2).....0.962
Standard Error of Estimate...........26.3
F-ratio..............................325

Figure 23. Auto Passenger Total From- Trips

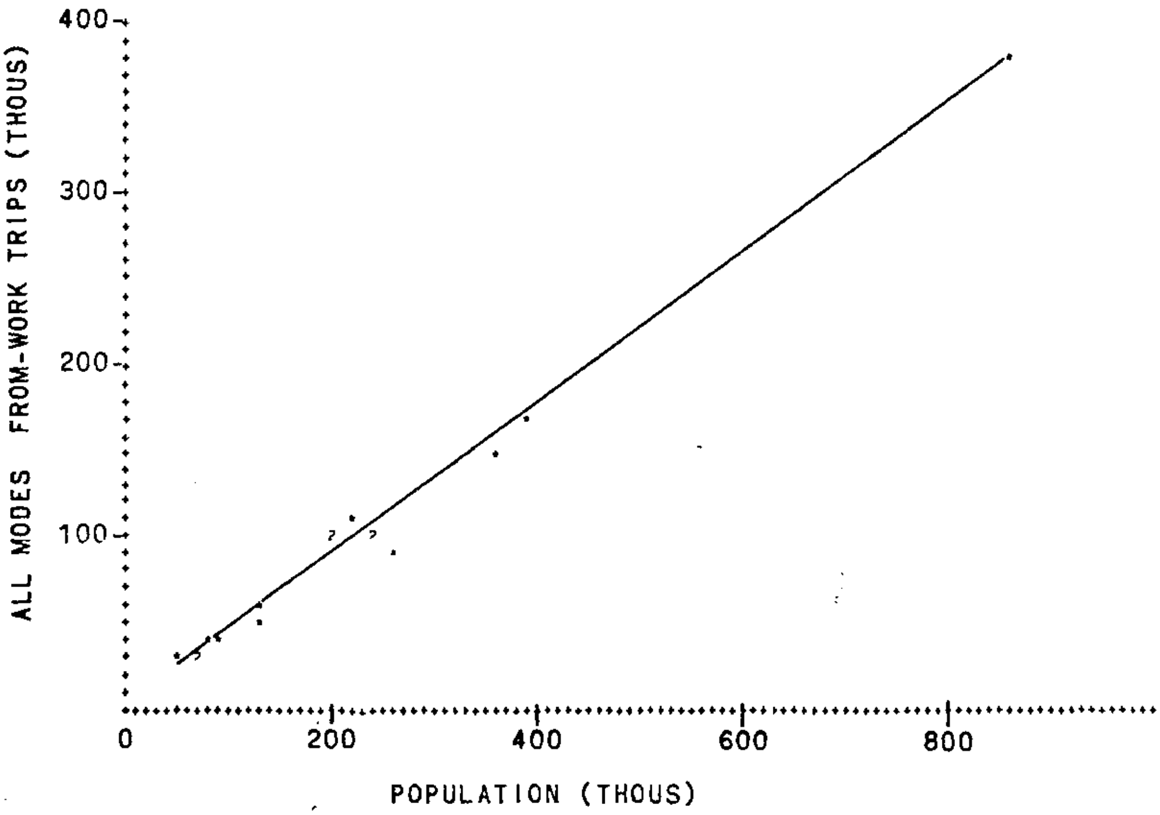
$Y = 15.18 + 0.833(X)$



Correlation Coefficient (R)........... 0.992
Coefficient of Determination (R^2)..... 0.984
Standard Error of Estimate............ 21.8
F-ratio............................... 857

Figure 24. All Modes From-home Trips

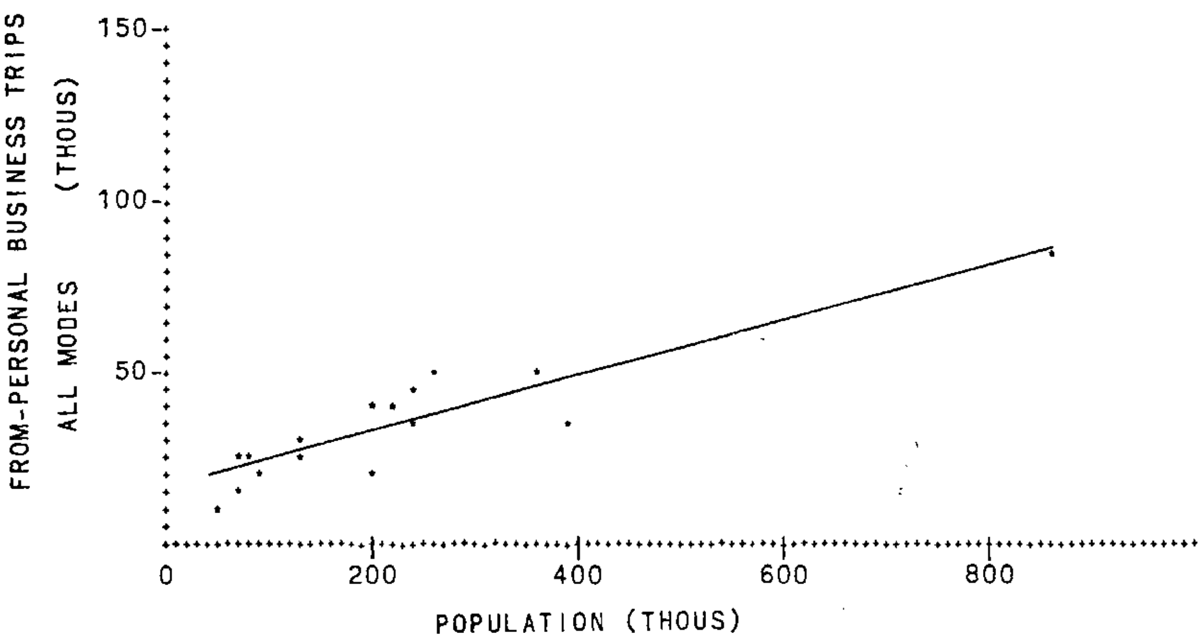
Y = -0.81 + 0.441(X)



Correlation Coefficient (R)	0.995
Coefficient of Determination (R^2)	0.989
Standard Error of Estimate	9.37
F-ratio	1294

Figure 25. All Modes From-work Trips

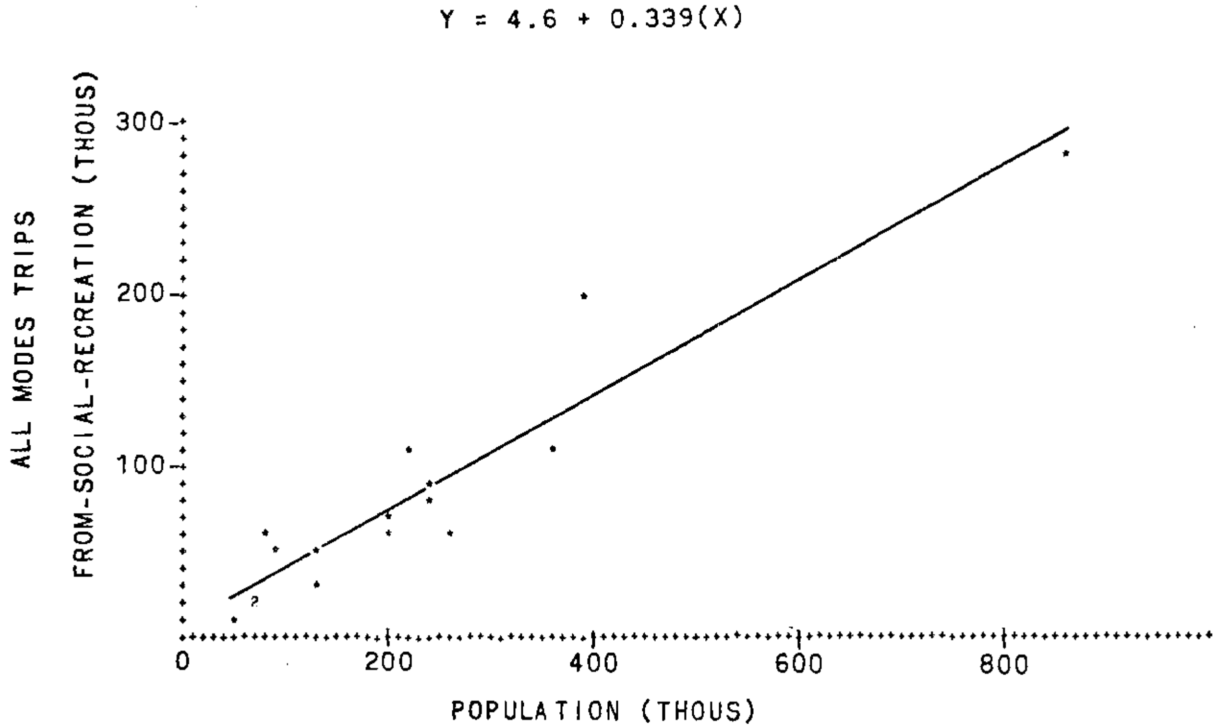
$Y = 15.2 + 0.0845(X)$



Correlation Coefficient (R)...........	0.887
Coefficient of Determination (R^2).....	0.788
Standard Error of Estimate............	8.96
F-ratio..............................	52

Figure 26.

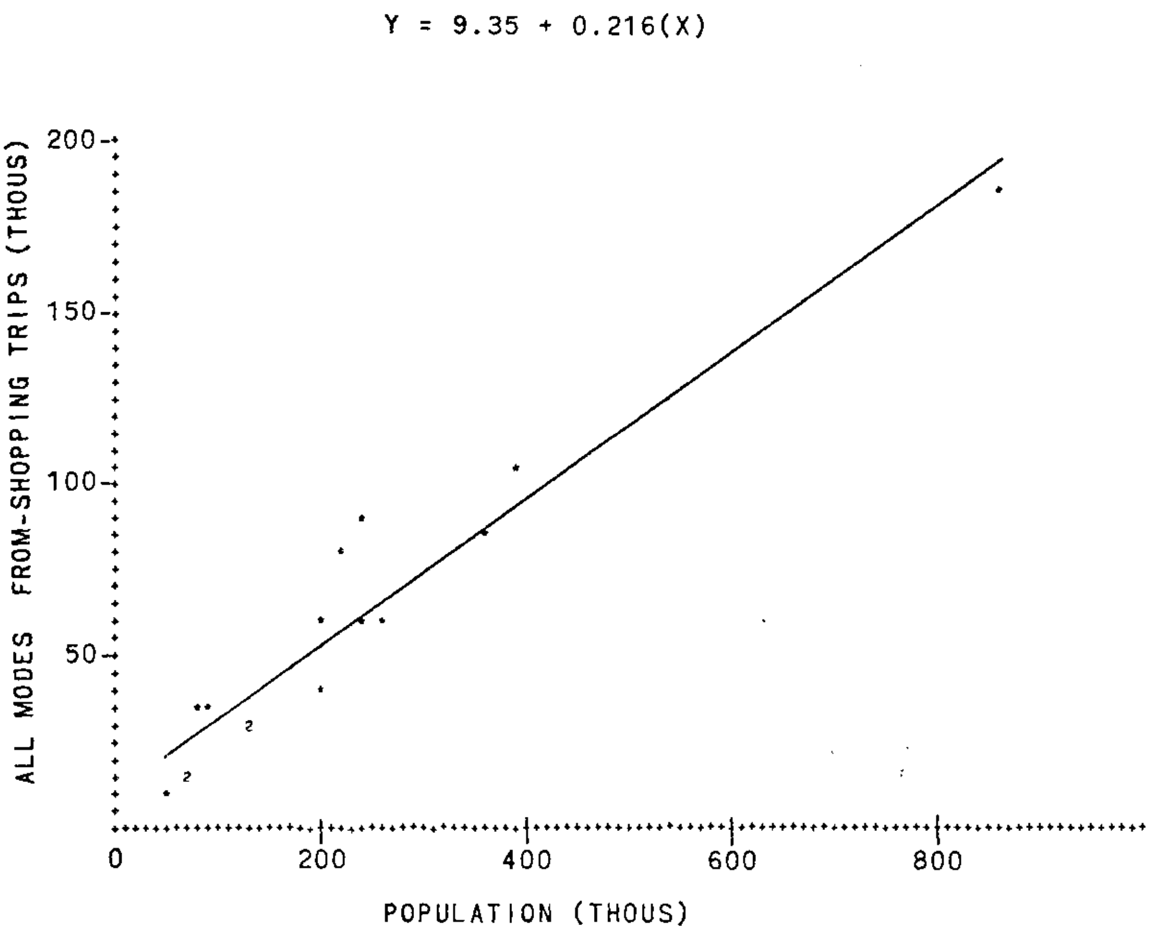
All Modes From-personal business Trips



Correlation Coefficient (R).......... 0.943
Coefficient of Determination (R^2).... 0.889
Standard Error of Estimate........... 24.5
F-ratio............................. 112

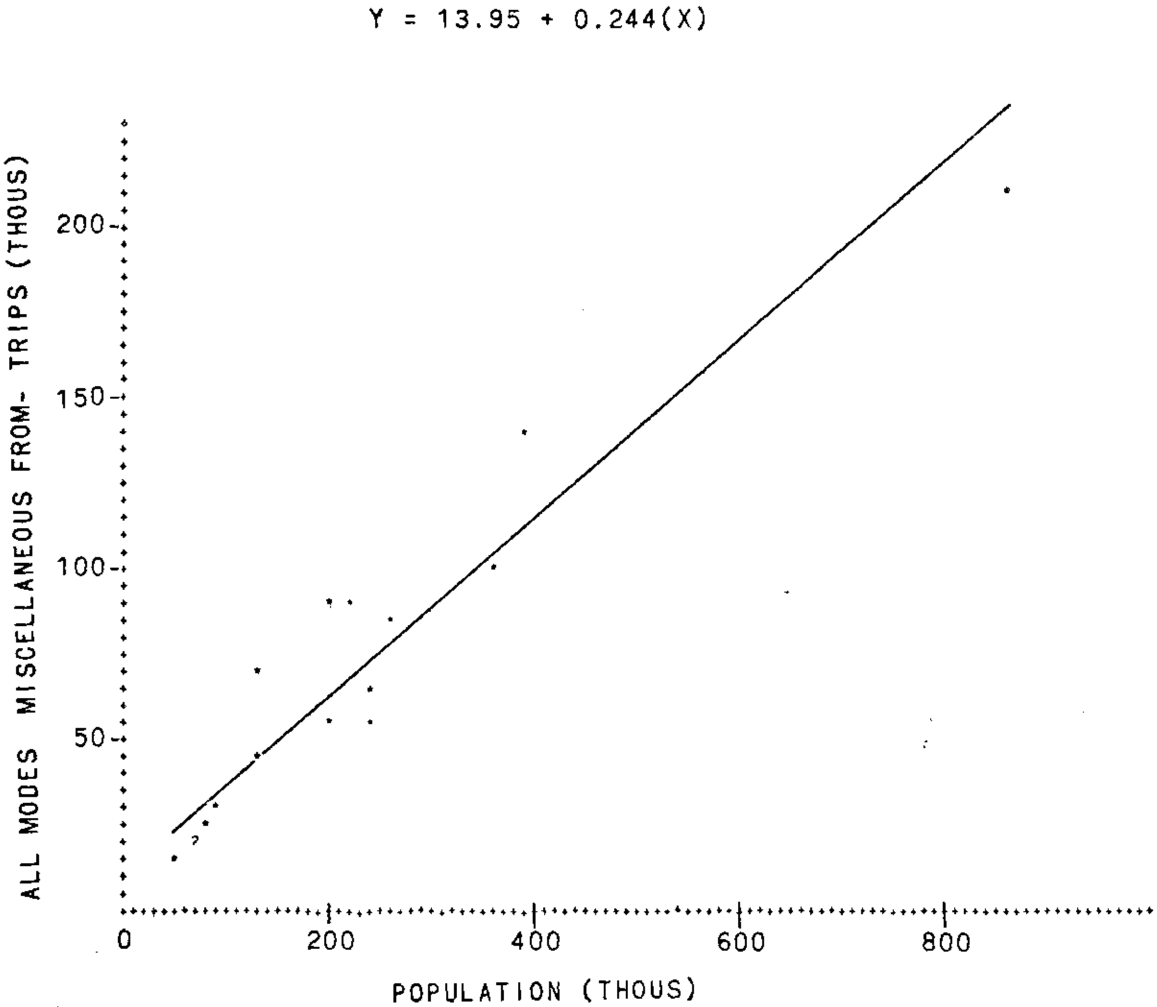
Figure 27.

All Modes From-social-recreation Trips



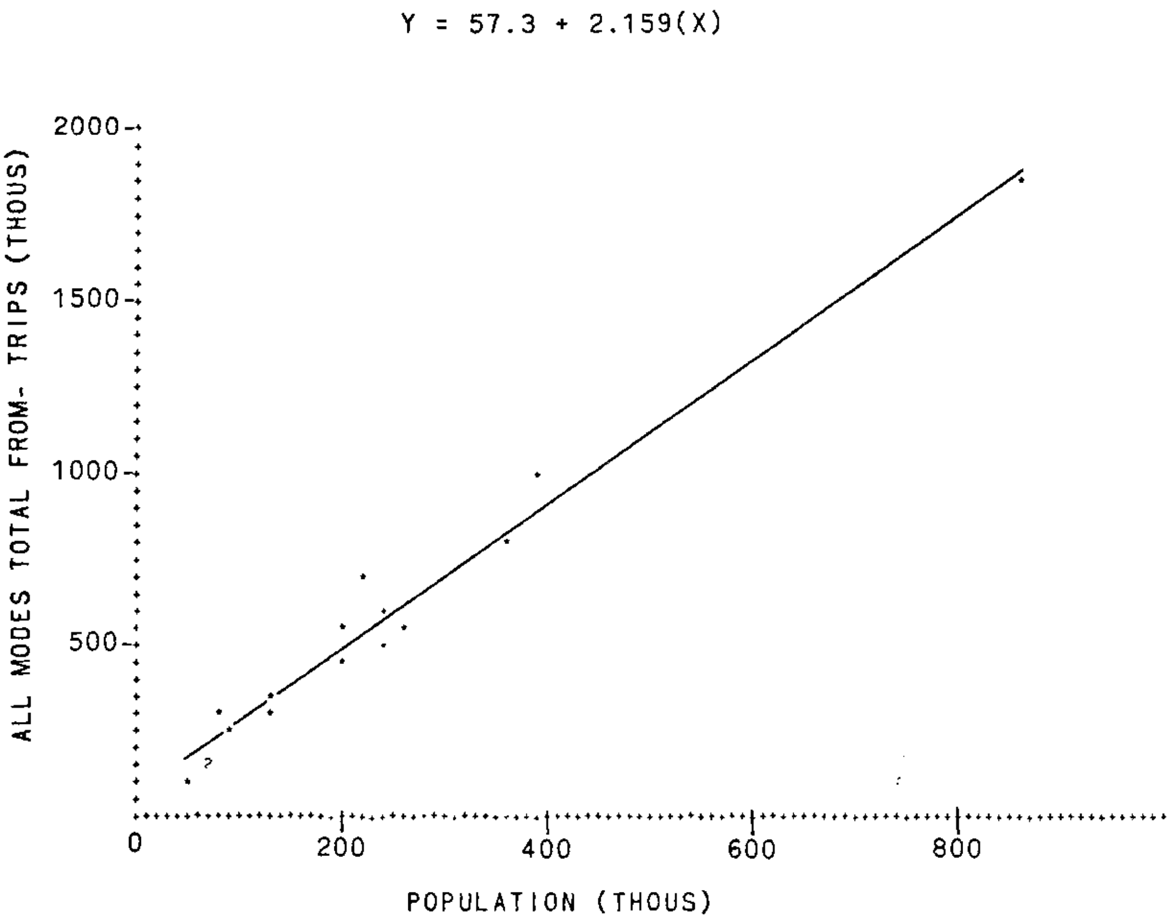
Correlation Coefficient (R)...........0.965
Coefficient of Determination (R^2).....0.932
Standard Error of Estimate............11.9
F-ratio..............................192

Figure 28. All Modes From-shopping Trips



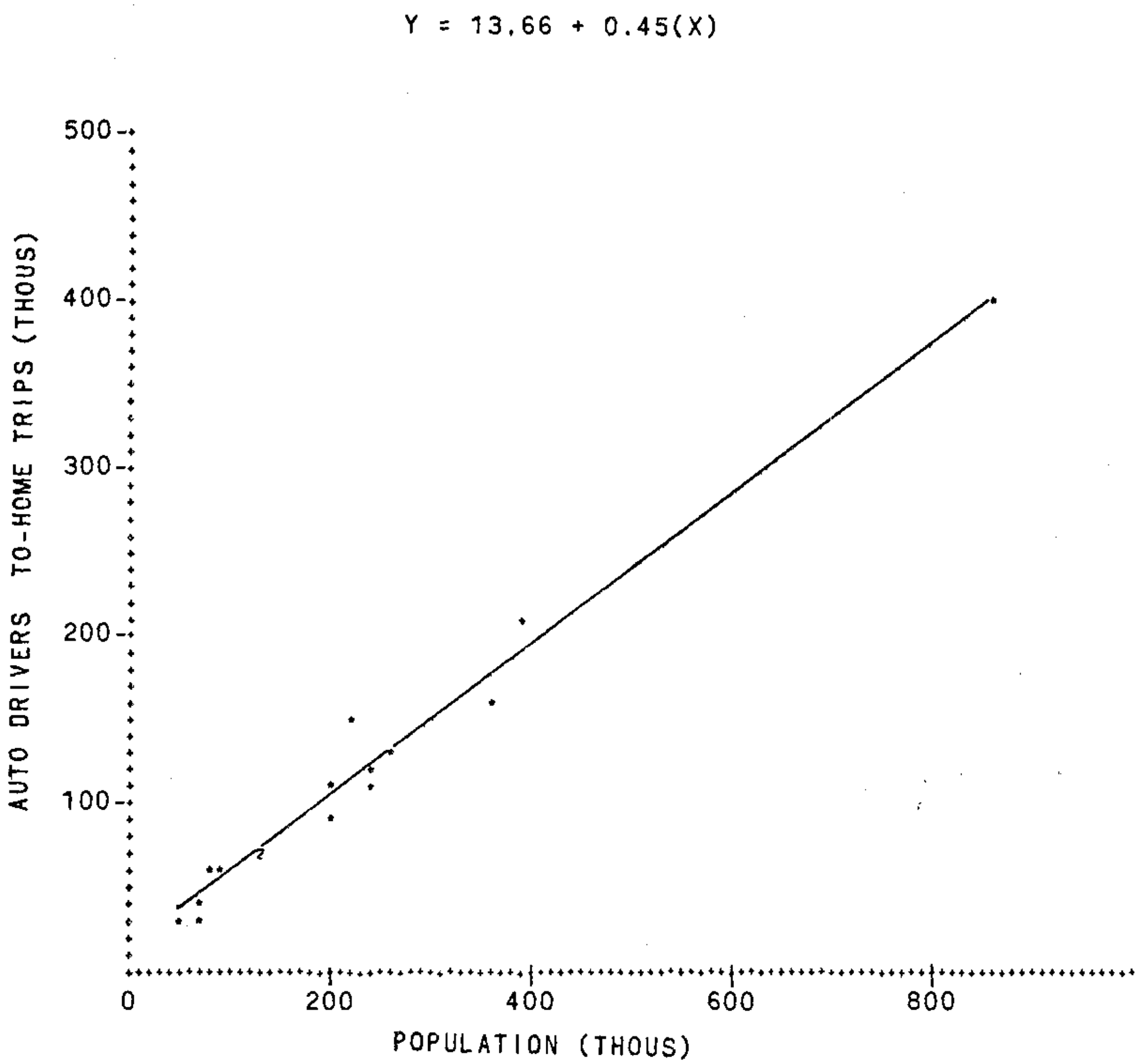
Correlation Coefficient (R)........... 0.954
Coefficient of Determination (R^2)..... 0.909
Standard Error of Estimate............ 15.8
F-ratio.............................. 140

Figure 29. All Modes Miscellaneous From- Trips



Correlation Coefficient (R)........... 0.989
Coefficient of Determination (R^2)..... 0.978
Standard Error of Estimate............ 65.7
F-ratio............................... 631

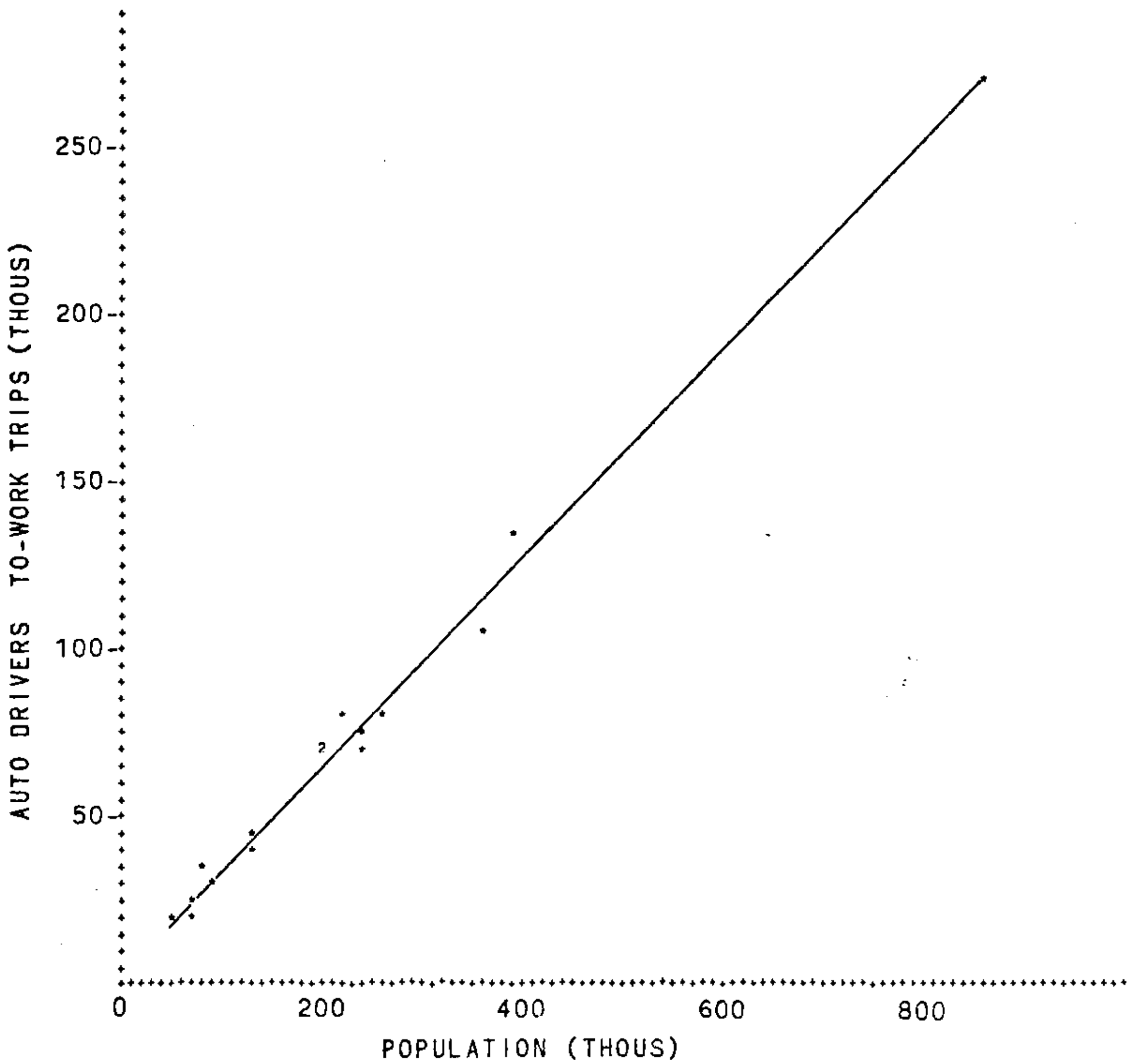
Figure 30. All Modes Total From- Trips



Correlation Coefficient (R)...........0.989
Coefficient of Determination (R^2).....0.979
Standard Error of Estimate...........13.6
F-ratio............................ 64

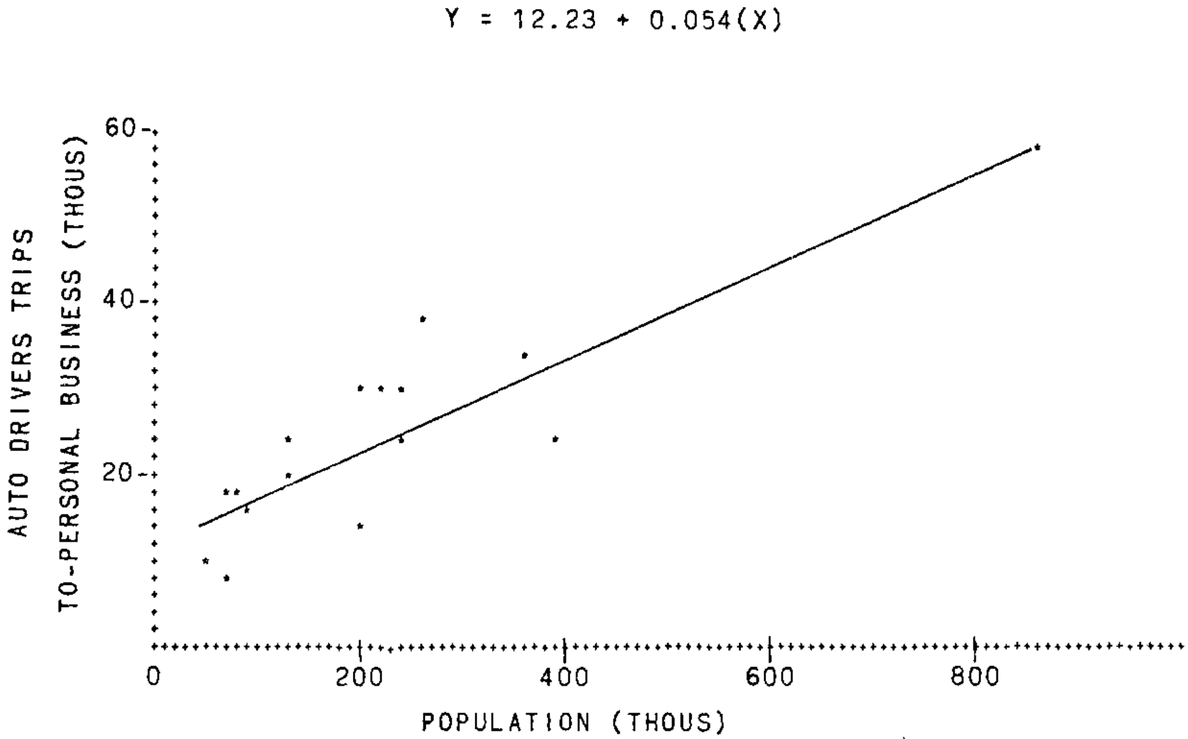
Figure 31. Auto Driver To-home Trips

$Y = 3.61 + 0.308(X)$



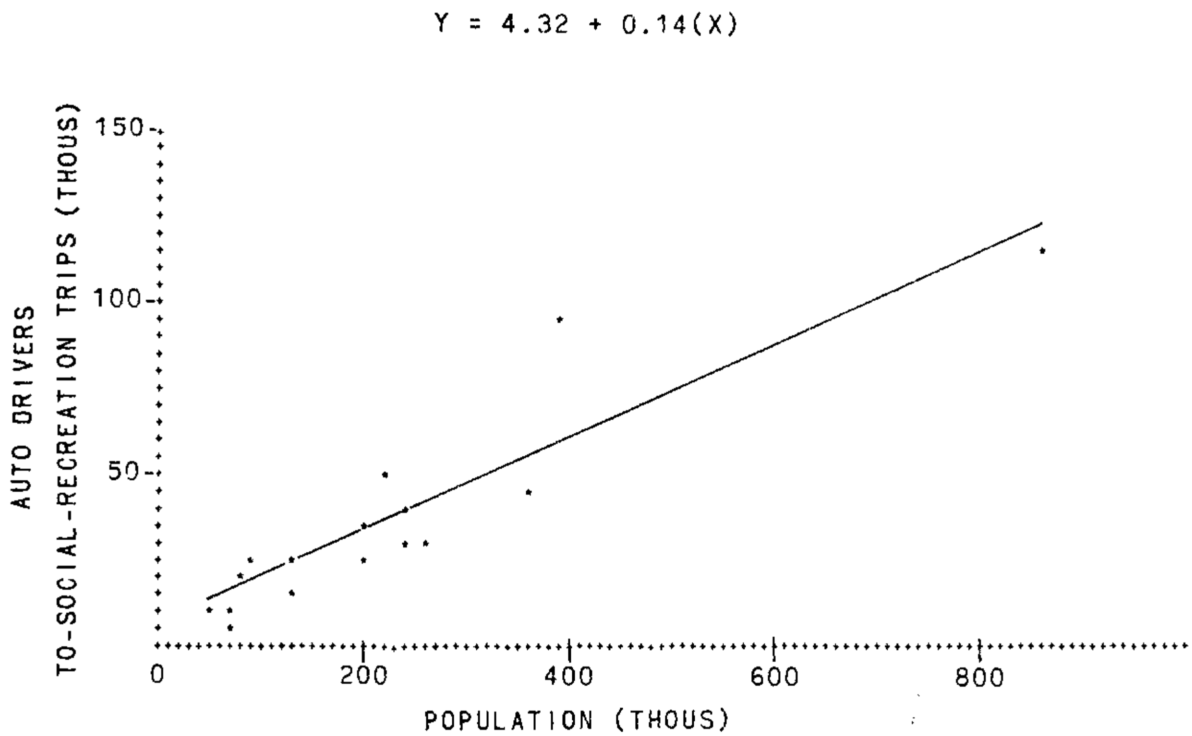
Correlation Coefficient (R)...........	0.995
Coefficient of Determination (R^2).....	0.990
Standard Error of Estimate............	6.44
F-ratio.............................	1330

Figure 32. Auto Driver To-work Trips



Correlation Coefficient (R)..........0.872
Coefficient of Determination (R^2)....0.761
Standard Error of Estimate...........6.18
F-ratio............................. 45

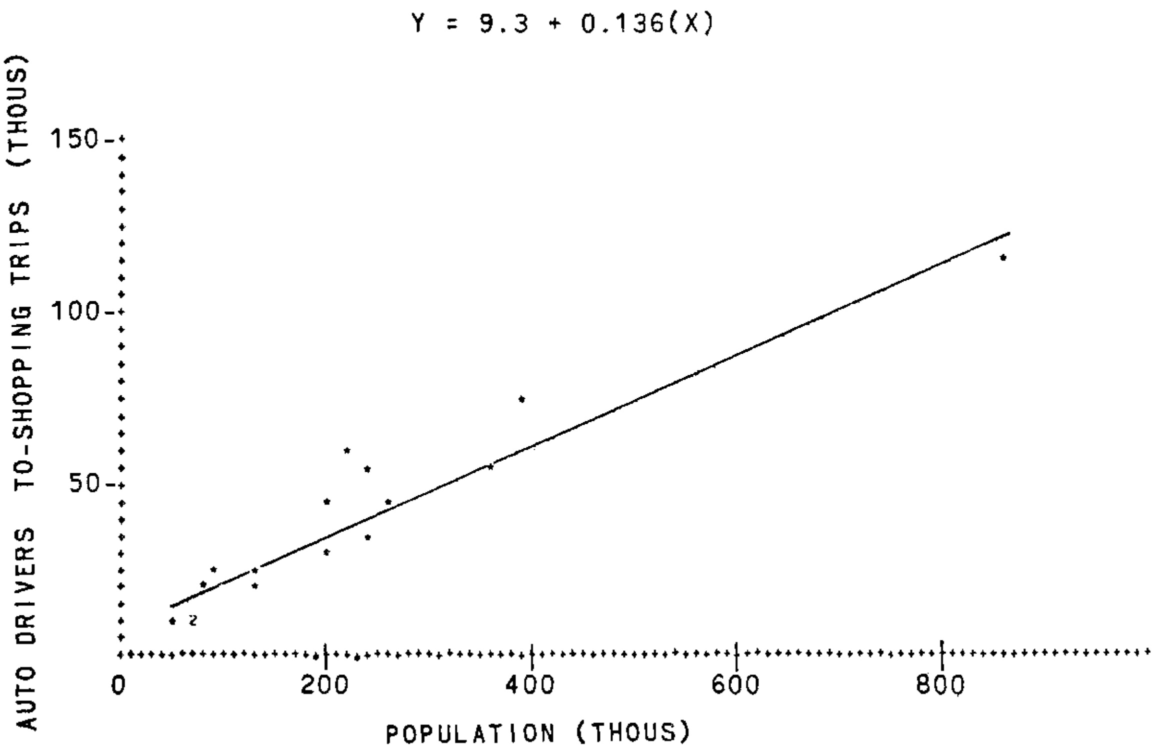
Figure 33. Auto Driver
To-personal business Trips



Correlation Coefficient (R)........... 0.920
Coefficient of Determination (R^2)..... 0.847
Standard Error of Estimate........... 12.2
F-ratio............................. 77

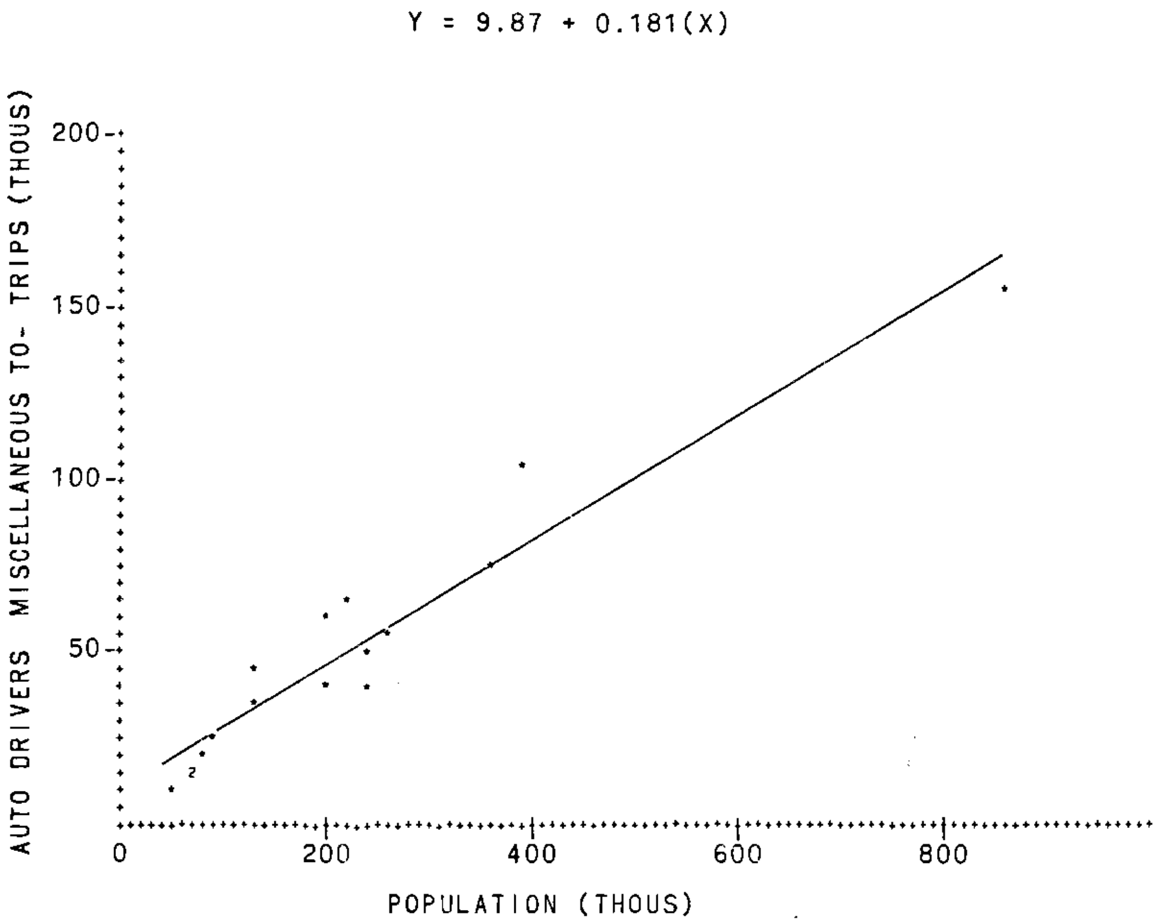
Figure 34. Auto Driver

To-social-recreation Trips



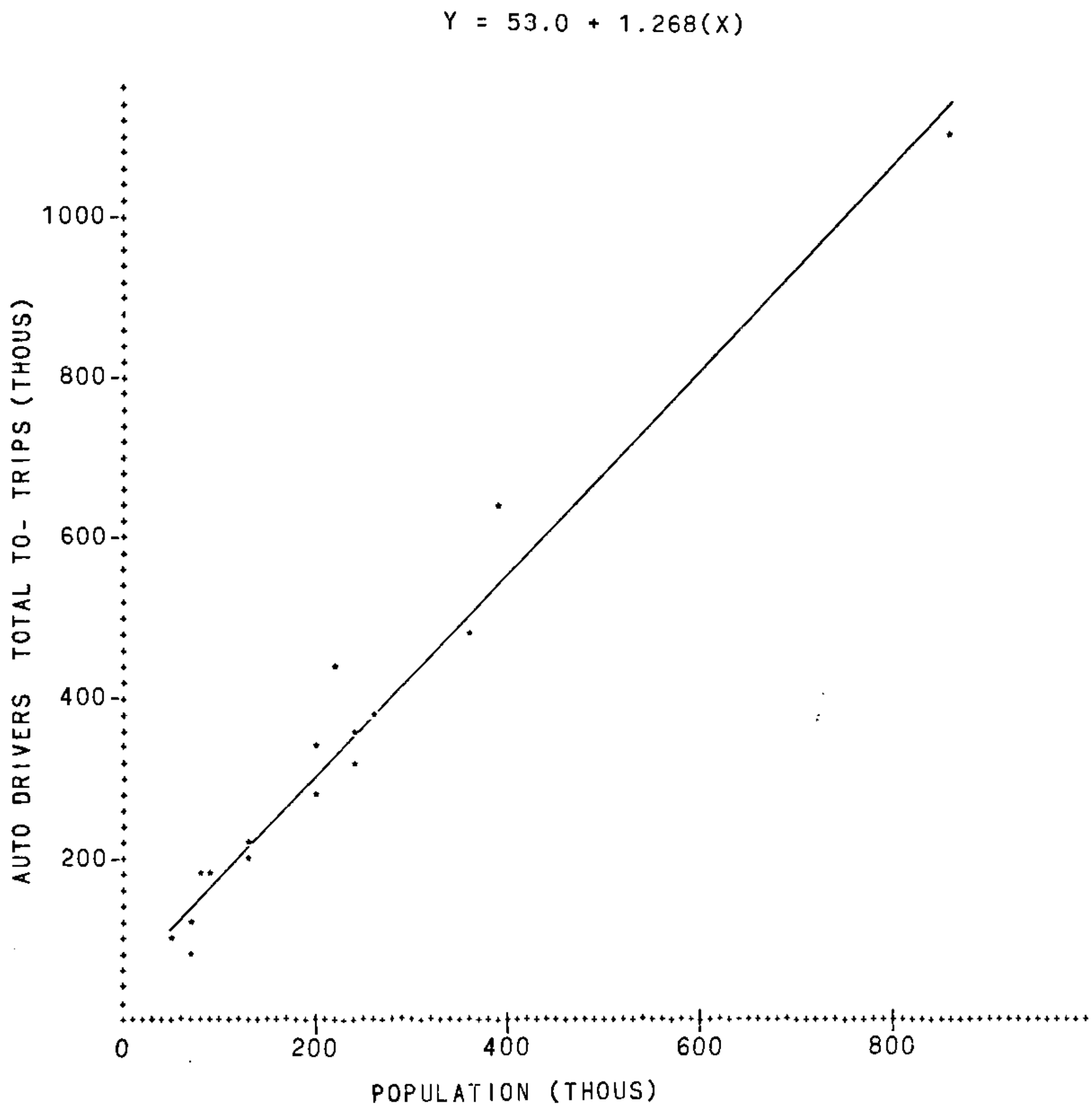
Correlation Coefficient (R)	0.955
Coefficient of Determination (R^2)	0.912
Standard Error of Estimate	8.6
F-ratio	146

Figure 35. Auto Driver To-shopping Trips



Correlation Coefficient (R)........... 0.958
Coefficient of Determination (R^2)..... 0.918
Standard Error of Estimate............ 11.05
F-ratio............................. 156

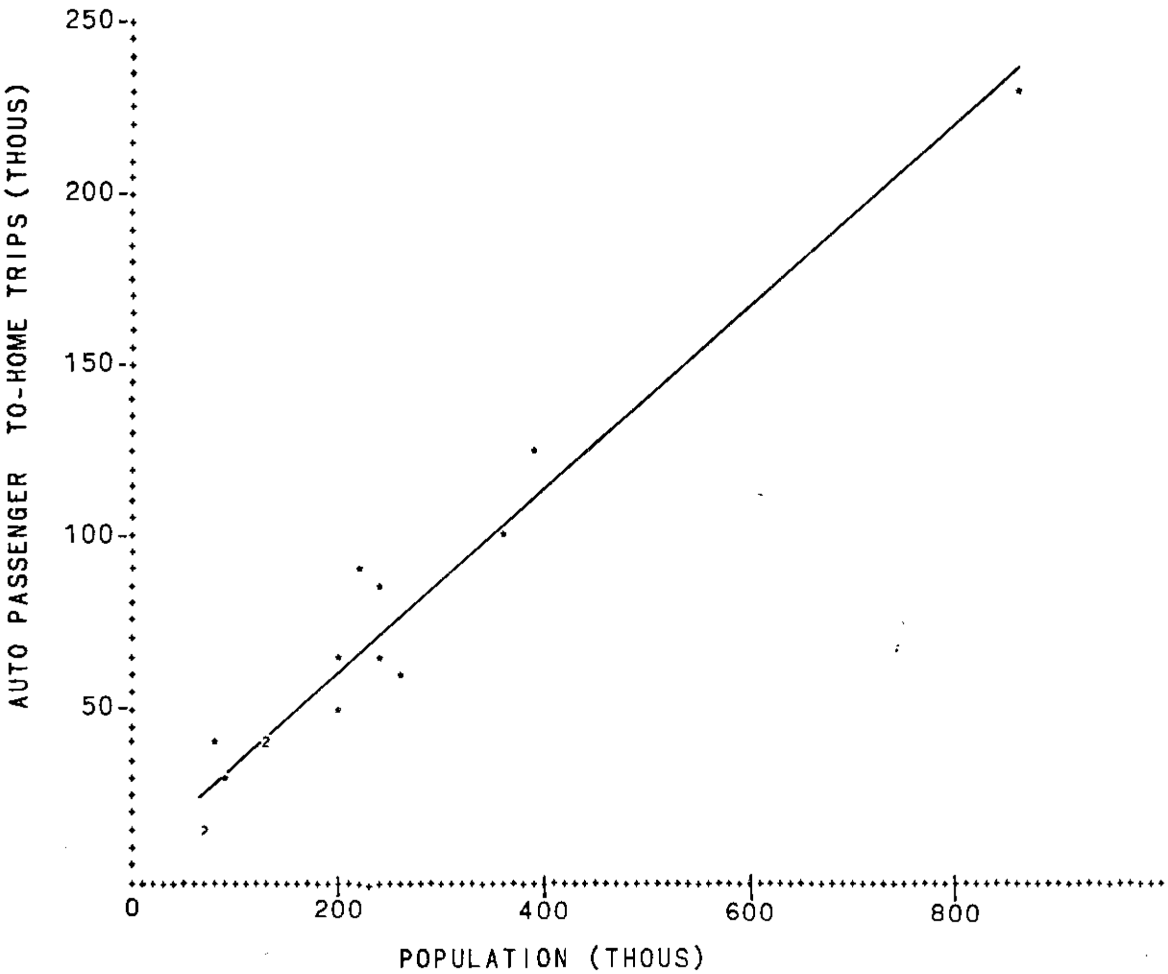
Figure 36. Auto Driver Miscellaneous To- Trips



Correlation Coefficient (R)...........	0.985
Coefficient of Determination (R^2).....	0.970
Standard Error of Estimate............	45.2
F-ratio...............................	460

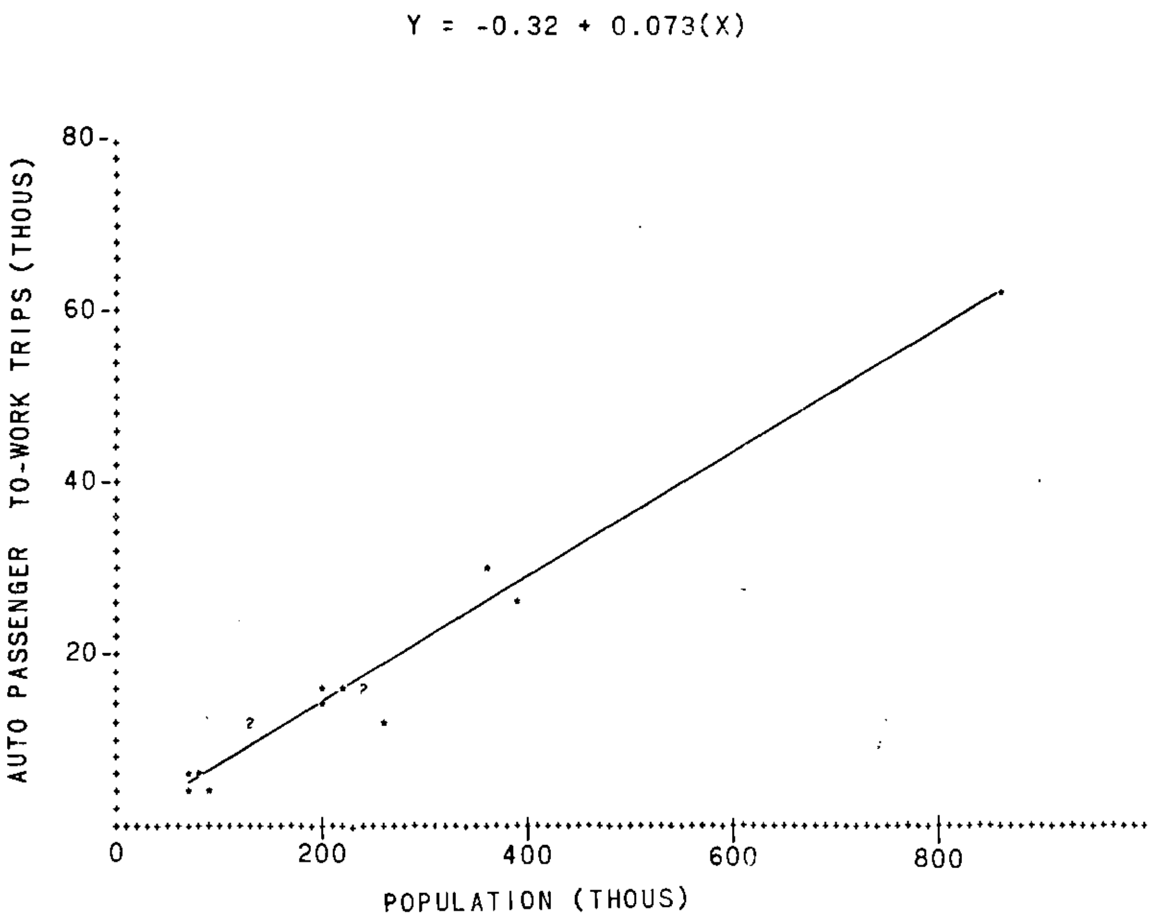
Figure 37. Auto Driver Total To- Trips

Y = 6.68 + 0.268(X)



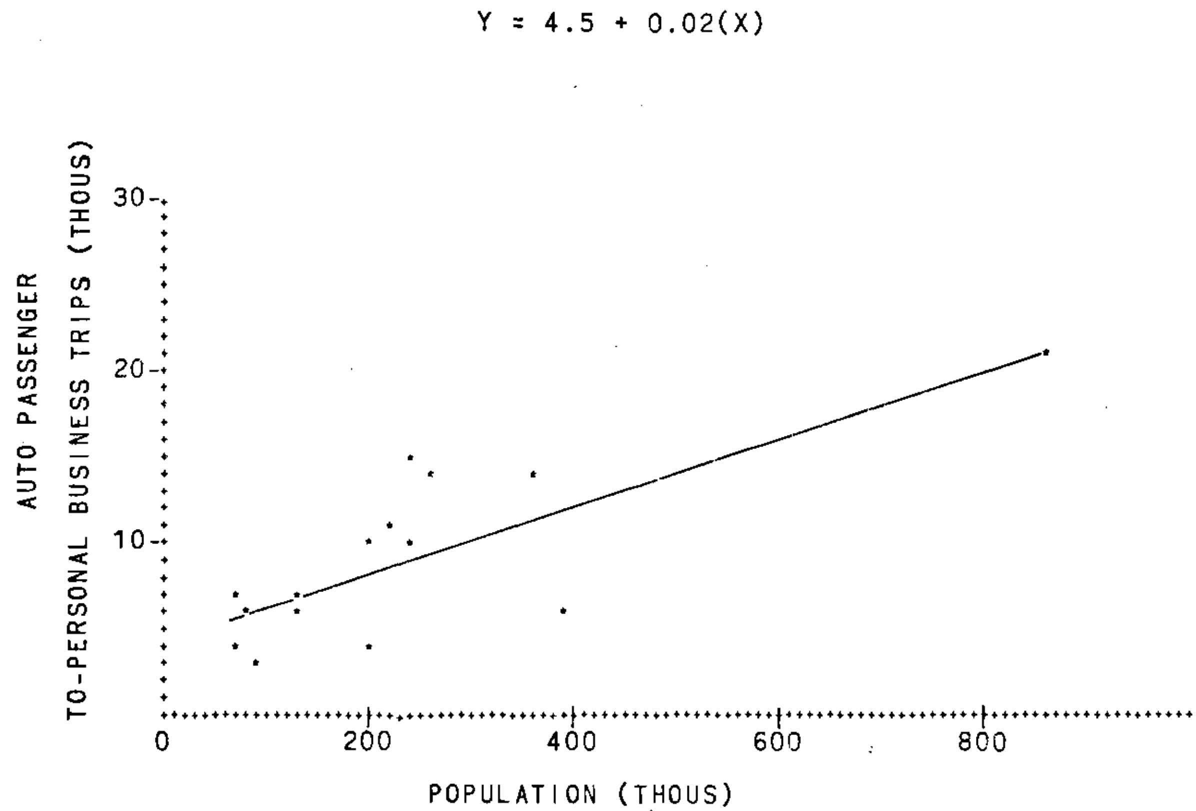
Correlation Coefficient (R)...........0.981
Coefficient of Determination (R^2).....0.963
Standard Error of Estimate............10.8
F-ratio.............................336

Figure 38. Auto Passenger To-home Trips



Correlation Coefficient (R)........... 0.985
Coefficient of Determination (R^2)..... 0.971
Standard Error of Estimate.... ...... 2.59
F-ratio............................ 436

Figure 39. Auto Passenger To-work Trips

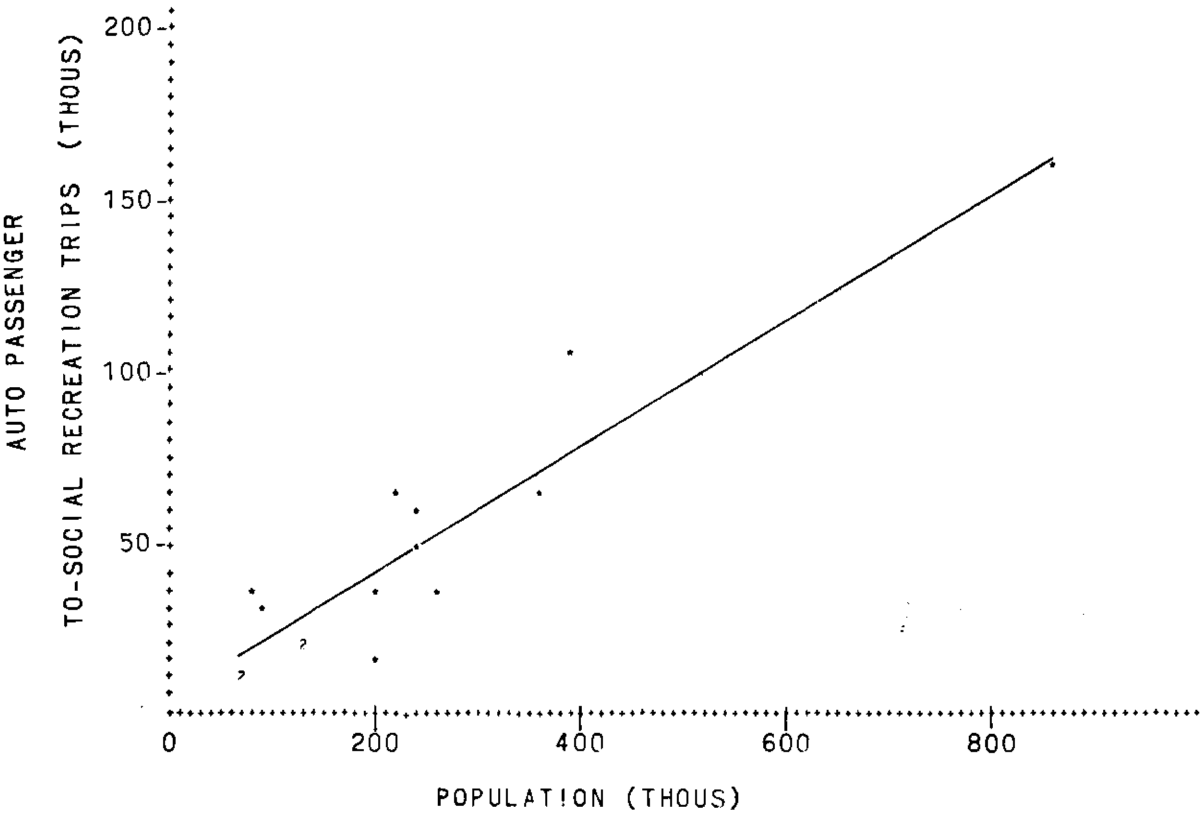


Correlation Coefficient (R)...........	0.780
Coefficient of Determination (R^2).....	0.608
Standard Error of Estimate............	3.24
F-ratio............................	20

Figure 40.

Auto Passenger To-personal business Trips

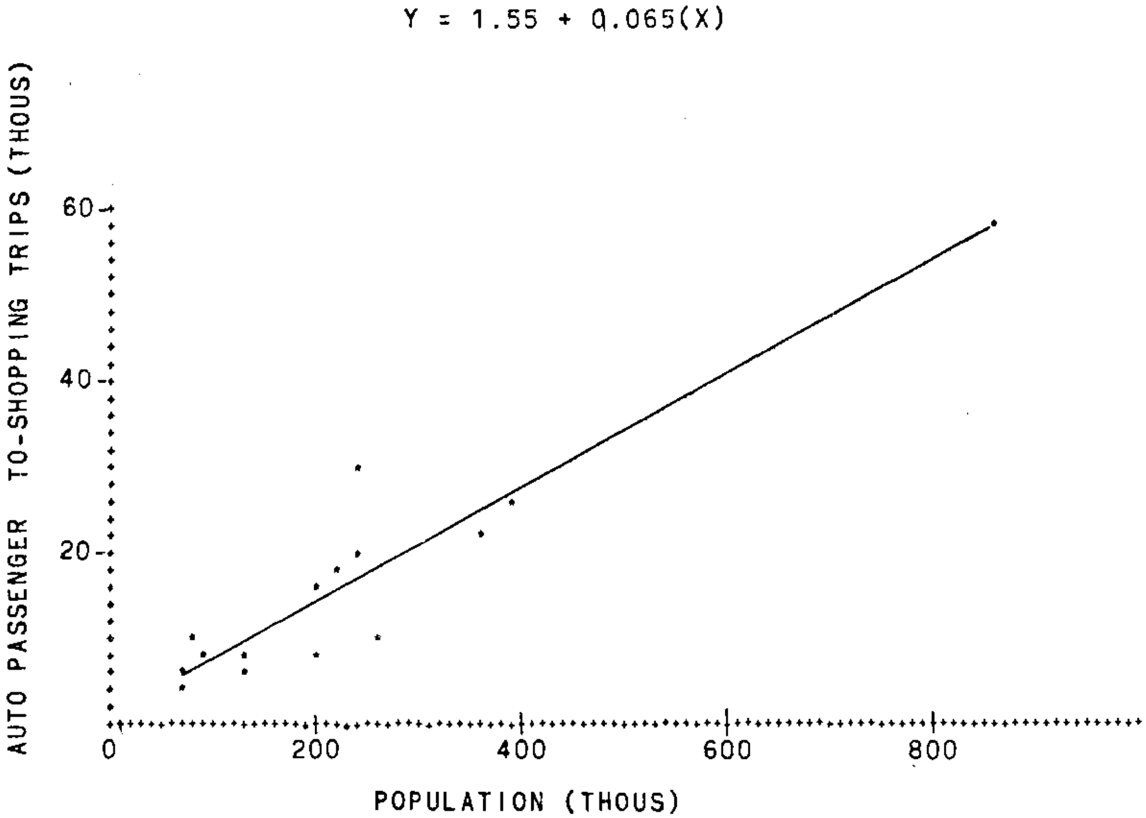
$$Y = 1.51 + 0.183(X)$$



Correlation Coefficient (R)...........	0.934
Coefficient of Determination (R2).....	0.872
Standard Error of Estimate............	14.4
F-ratio...............................	888

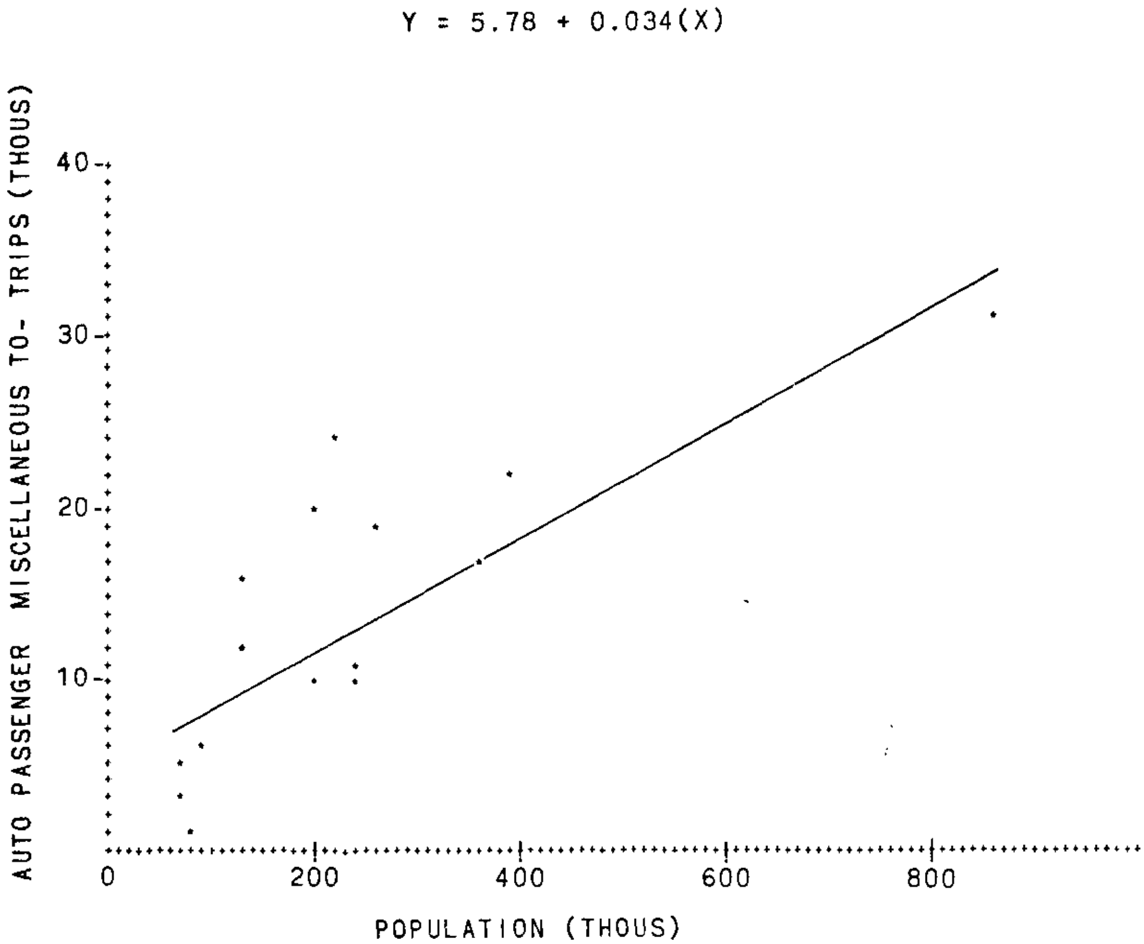
Figure 41.

Auto Passenger To-social-recreation Trips



Correlation Coefficient (R)........... 0.936
Coefficient of Determination (R^2)..... 0.876
Standard Error of Estimate............ 5.0
F-ratio.............................. 92

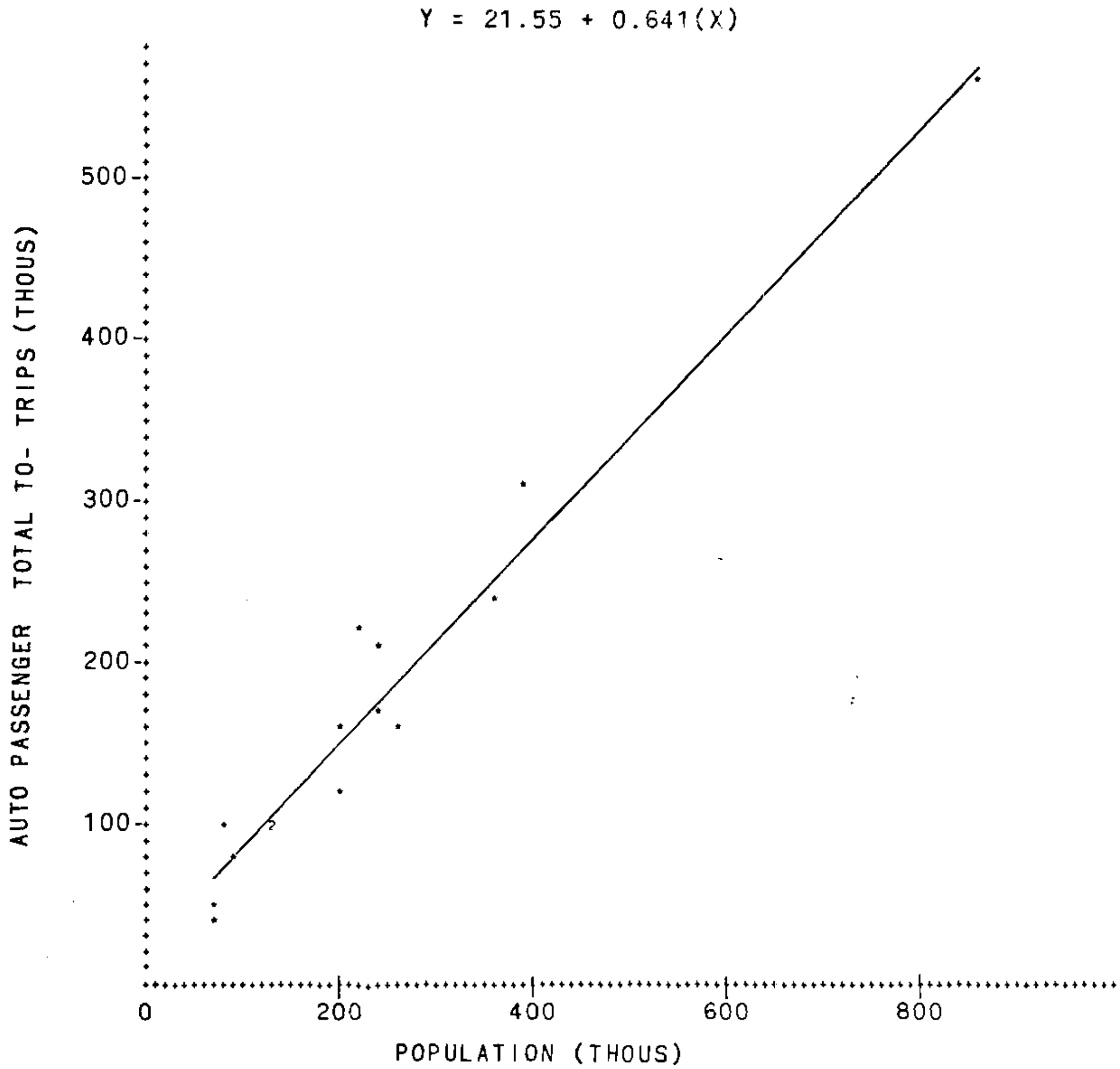
Figure 42. Auto Passenger To-shopping Trips



Correlation Coefficient (R)...........	0.787
Coefficient of Determination (R^2).....	0.619
Standard Error of Estimate............	5.45
F-ratio...............................	21

Figure 43. Auto Passenger

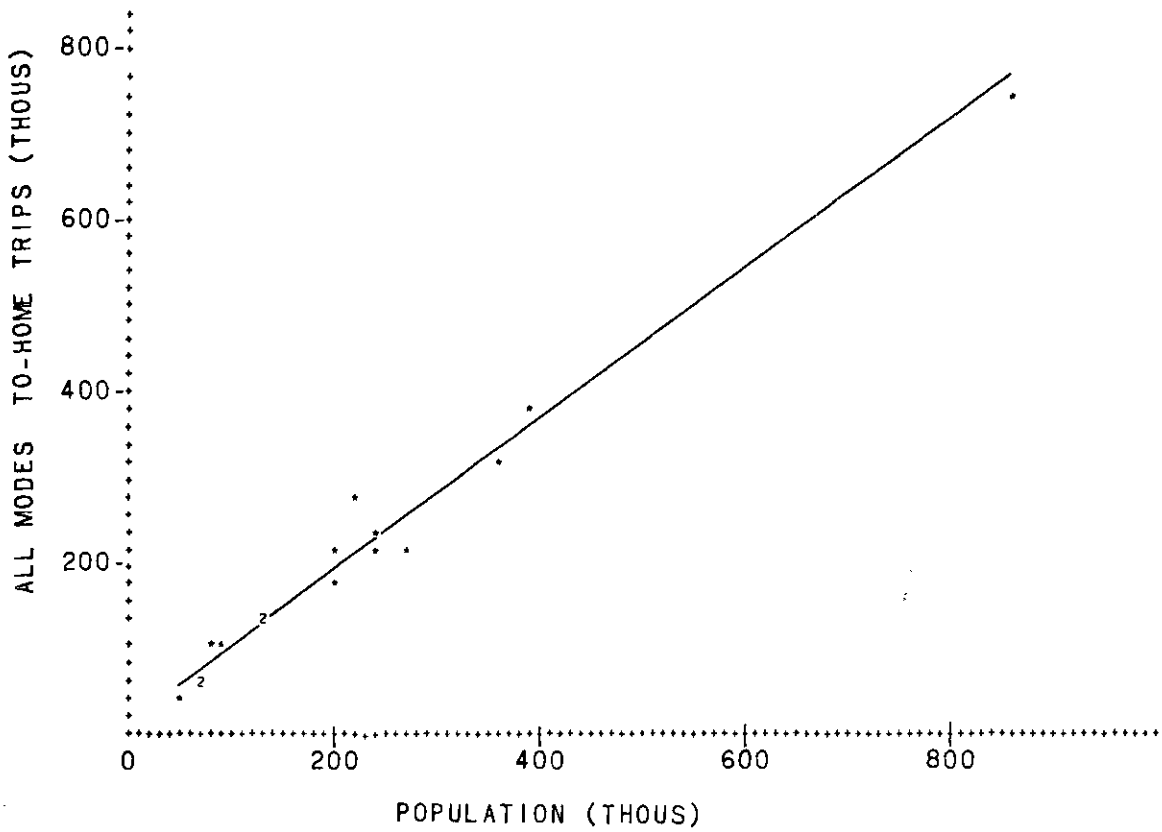
Miscellaneous To- Trips



Correlation Coefficient (R)........... 0.981
Coefficient of Determination (R^2)..... 0.962
Standard Error of Estimate............ 26.3
F-ratio............................. 325

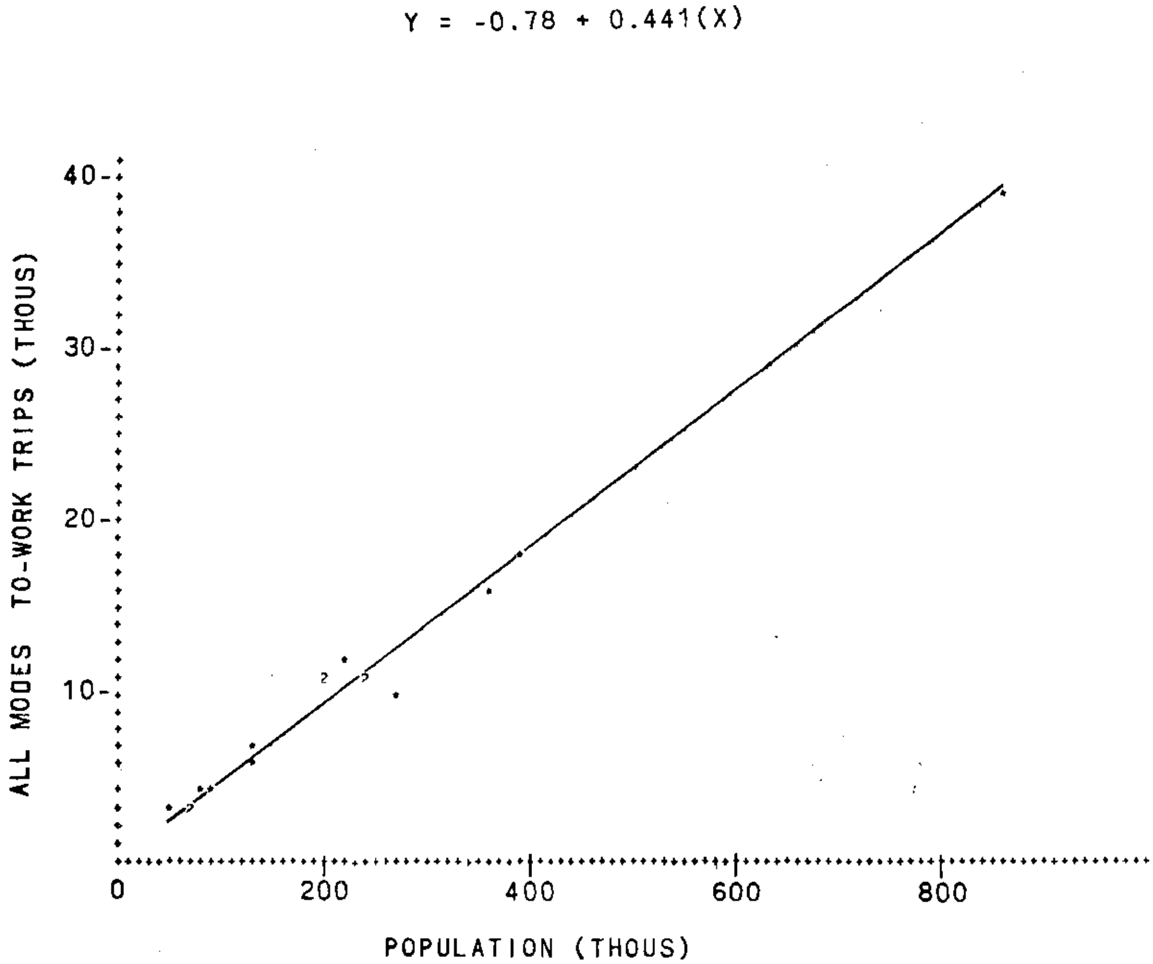
Figure 44. Auto Passenger Total To- Trips

Y = 12.57 + 0.830(X)



Correlation Coefficient (R)........... 0.991
Coefficient of Determination (R^2)..... 0.983
Standard Error of Estimate............ 22.3
F-ratio............................... 811

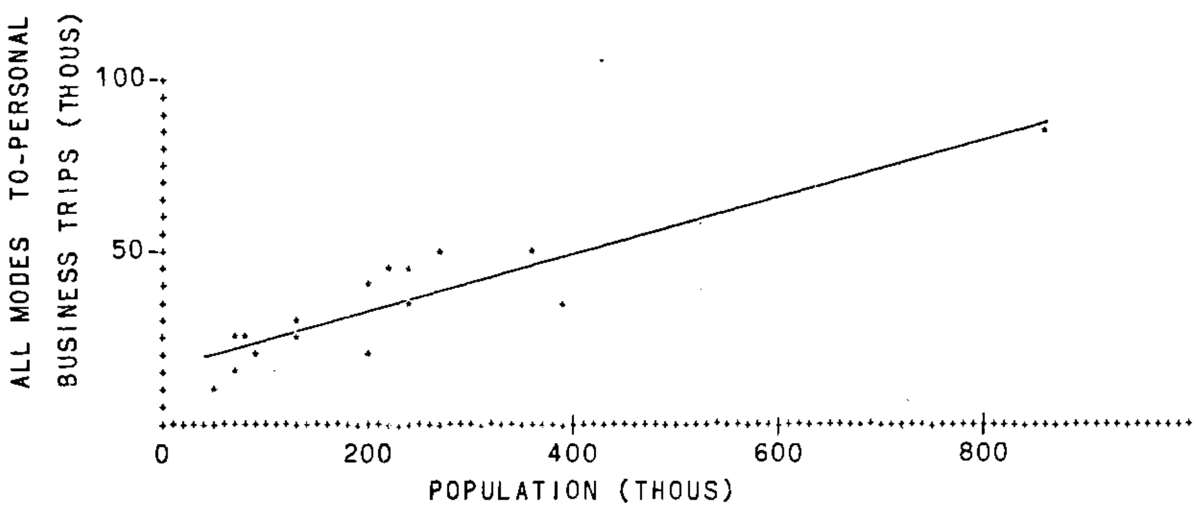
Figure 45. All Modes To-home Trips



Correlation Coefficient (R).......... 0.995
Coefficient of Determination (R^2)..... 0.990
Standard Error of Estimate........... 9.0
F-ratio.............................. 1400

Figure 46. All Modes To-work Trips

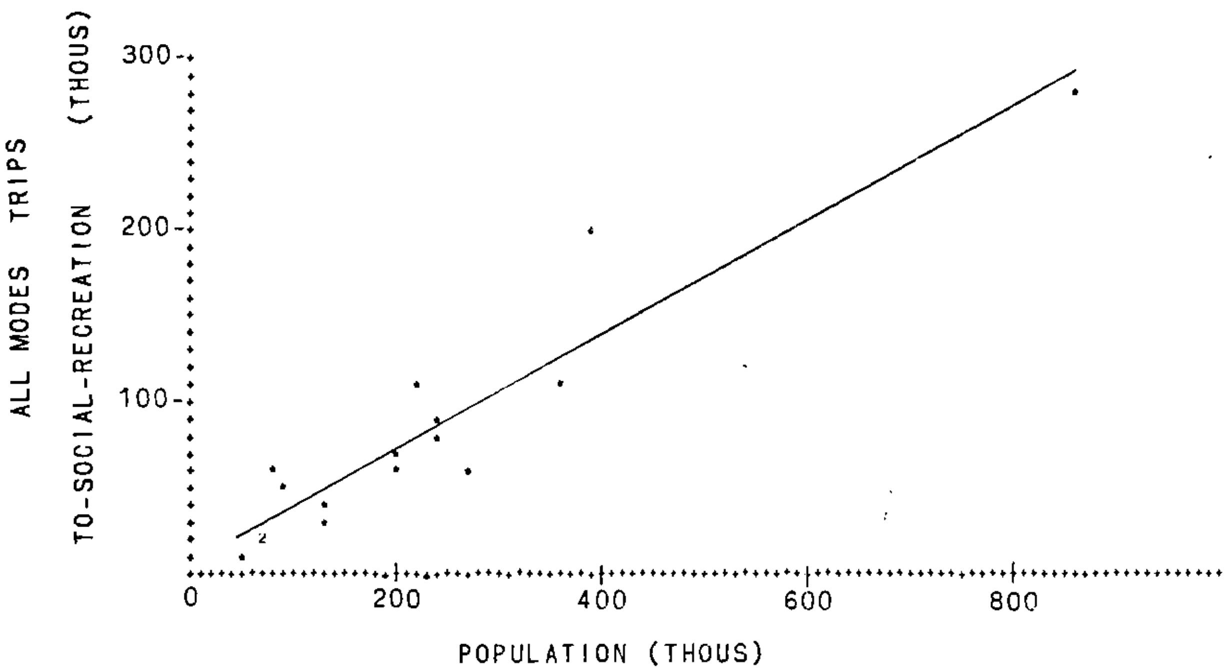
$Y = 15.64 + 0.084(X)$



Correlation Coefficient (R)........... 0.883
Coefficient of Determination (R^2)..... 0.780
Standard Error of Estimate............ 9.15
F-ratio.............................. 50

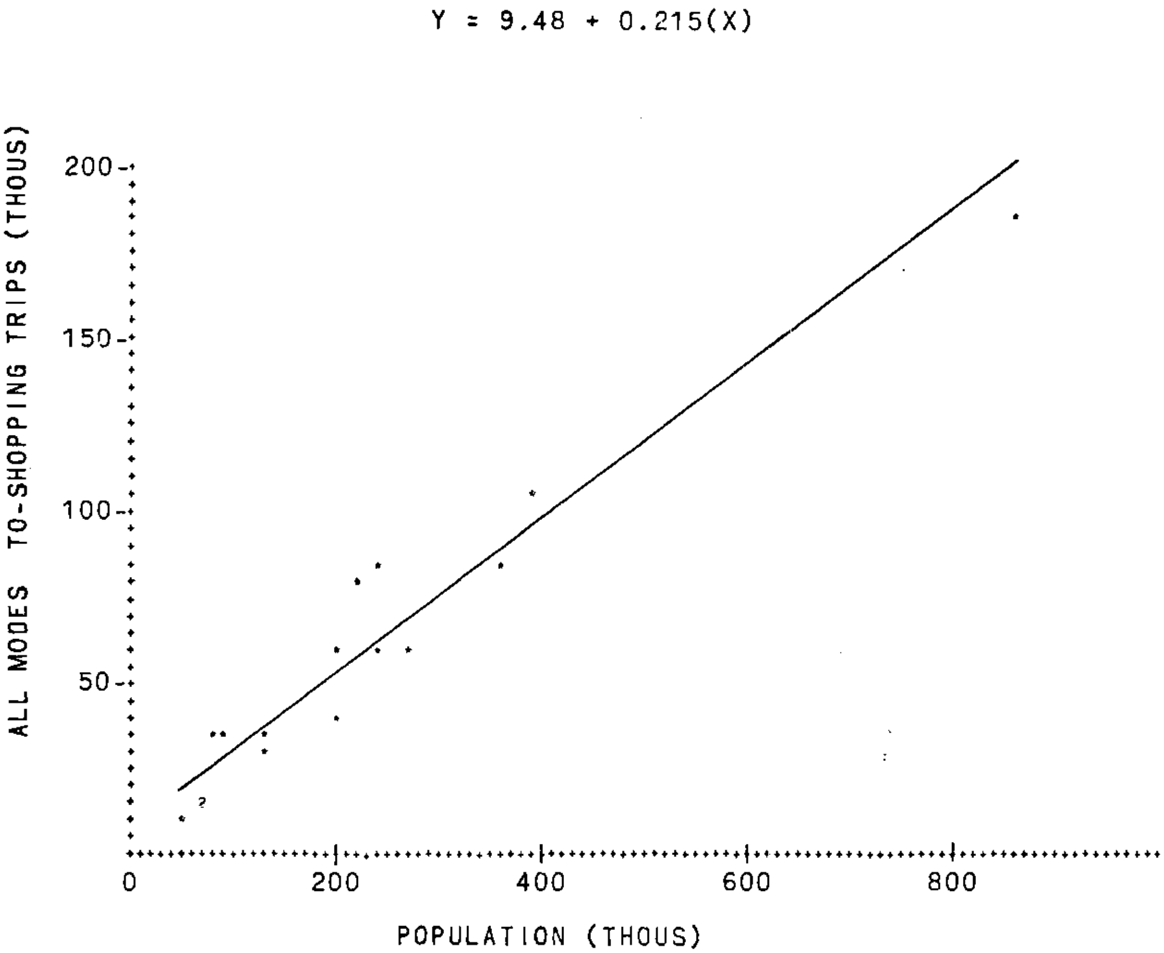
Figure 47. All Modes To-personal business Trips

$Y = 5.11 + 0.337(X)$



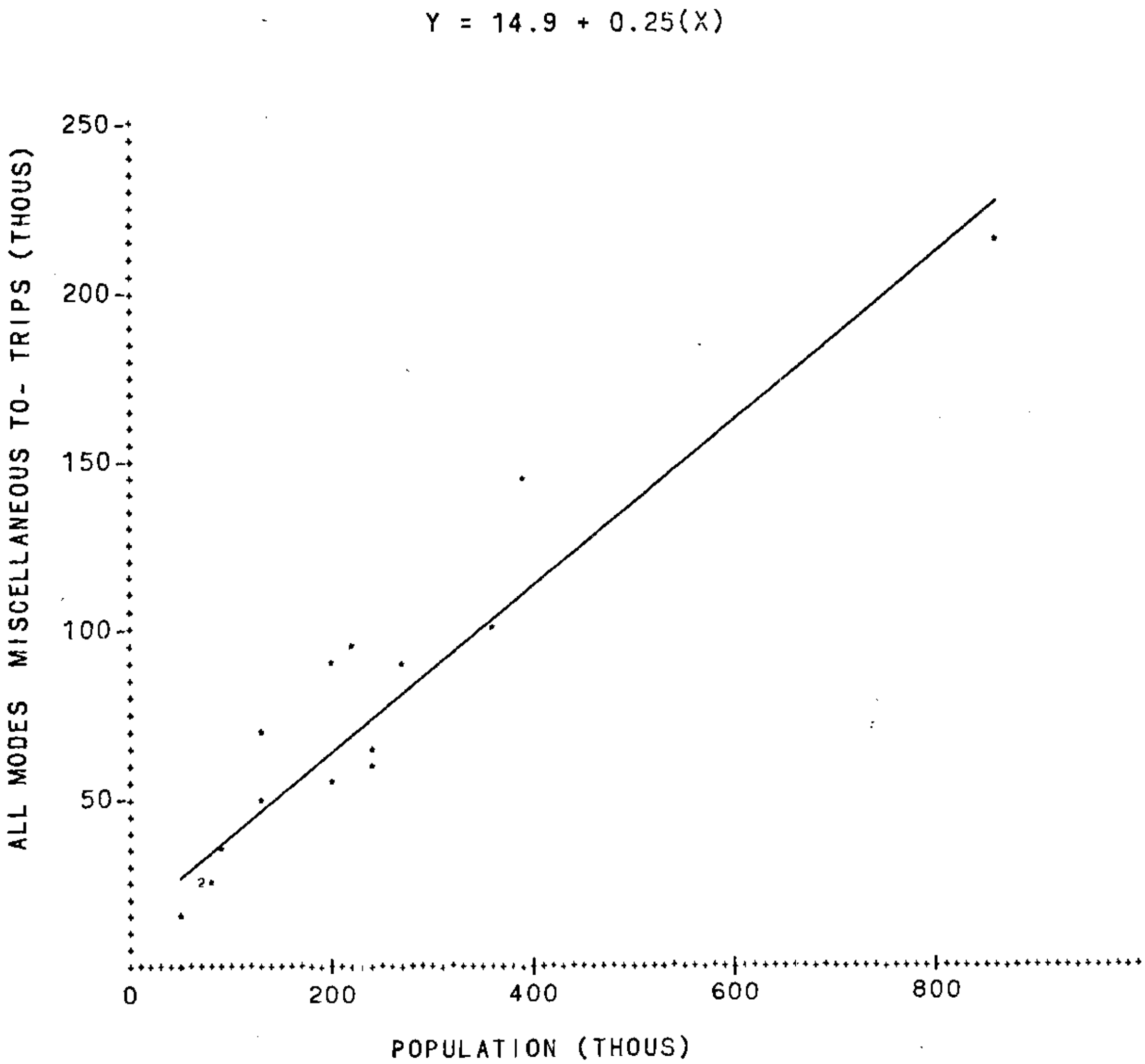
Correlation Coefficient (R)...........	0.944
Coefficient of Determination (R^2).....	0.891
Standard Error of Estimate............	24.2
F-ratio..............................	114

Figure 48. All Modes To-social-recreation Trips



Correlation Coefficient (R)........... 0.966
Coefficient of Determination (R^2)..... 0.933
Standard Error of Estimate............ 11.8
F-ratio............................. 194

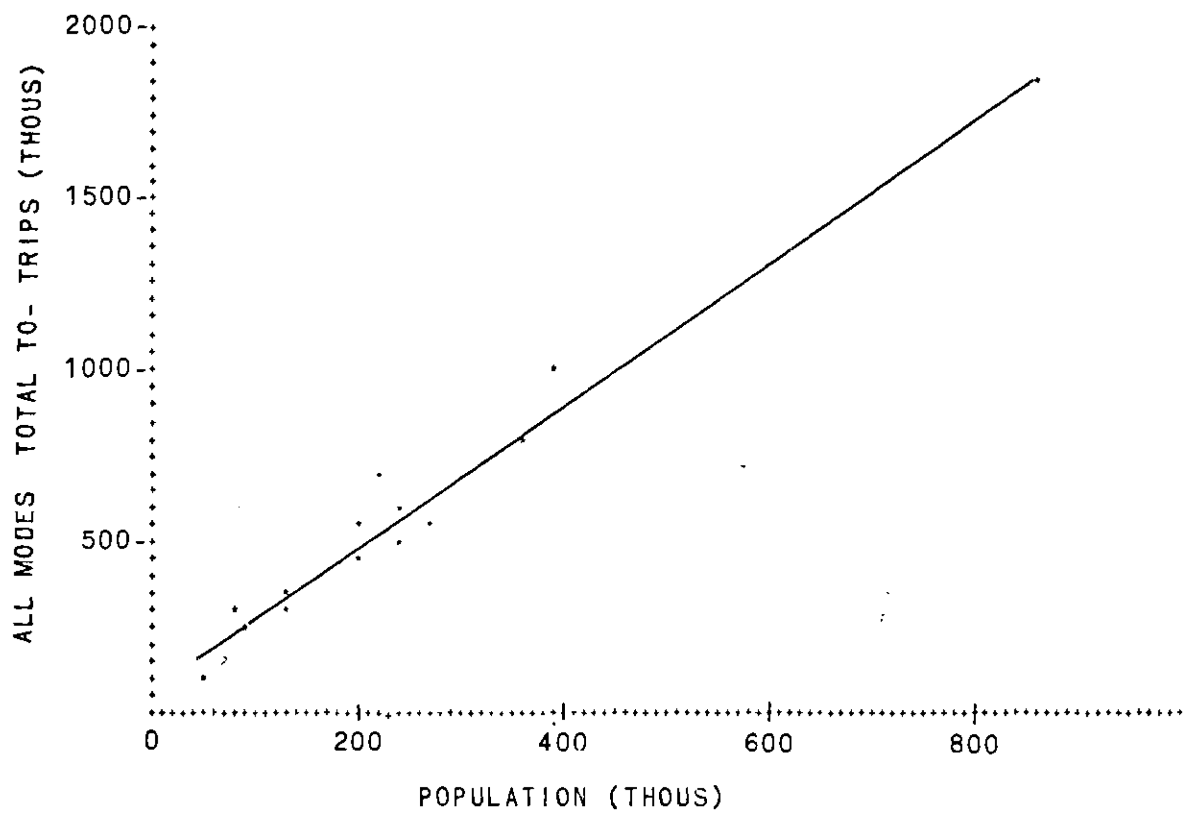
Figure 49. All Modes To-shopping Trips



Correlation Coefficient (R)...........	0.949
Coefficient of Determination (R^2).....	0.901
Standard Error of Estimate............	16.9
F-ratio...............................	127

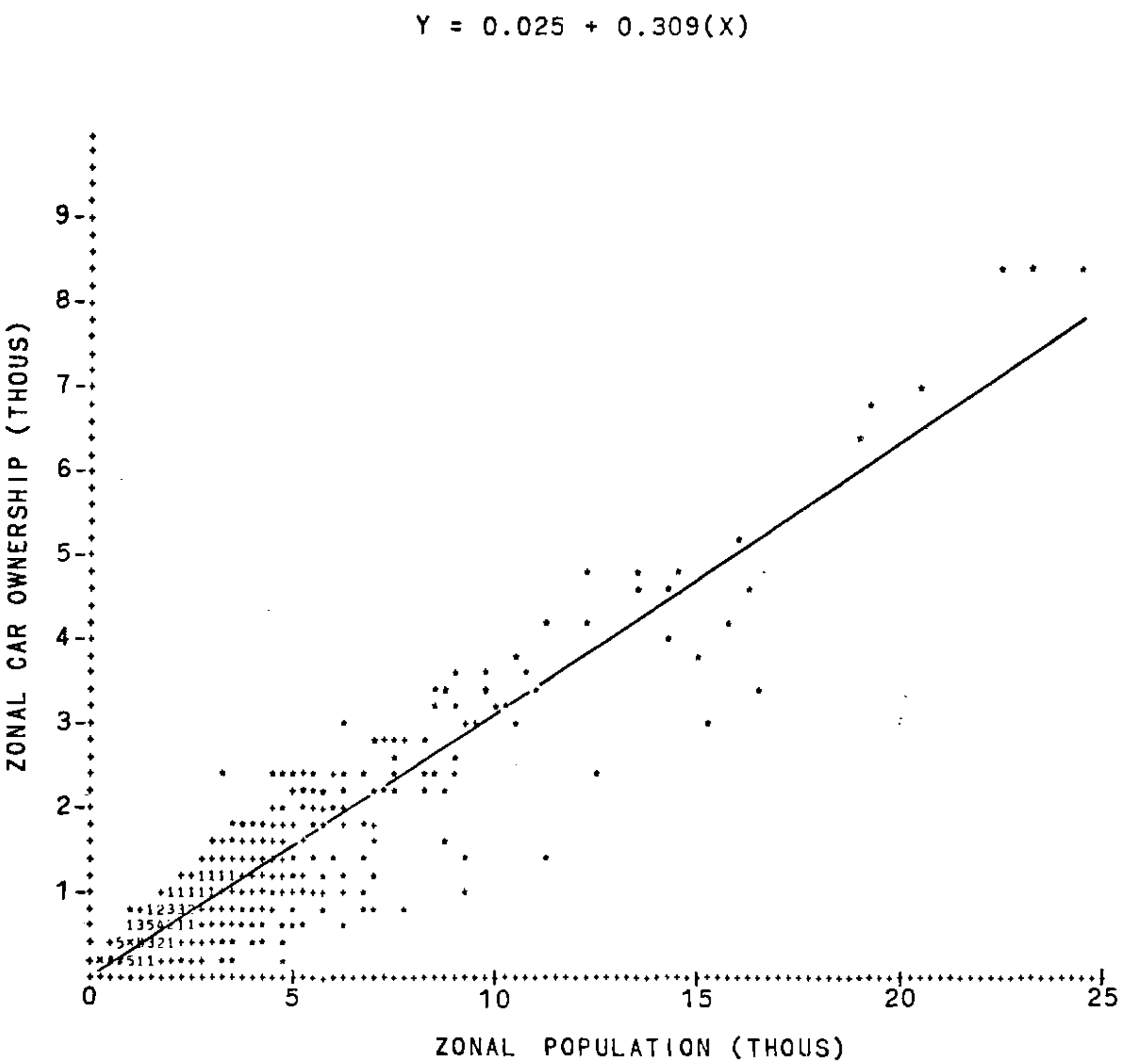
Figure 50. All Modes Miscellaneous To- Trips

$Y = 56.9 + 2.158(X)$



Correlation Coefficient (R)...........	0.989
Coefficient of Determination (R^2).....	0.978
Standard Error of Estimate............	66.3
F-ratio..............................	618

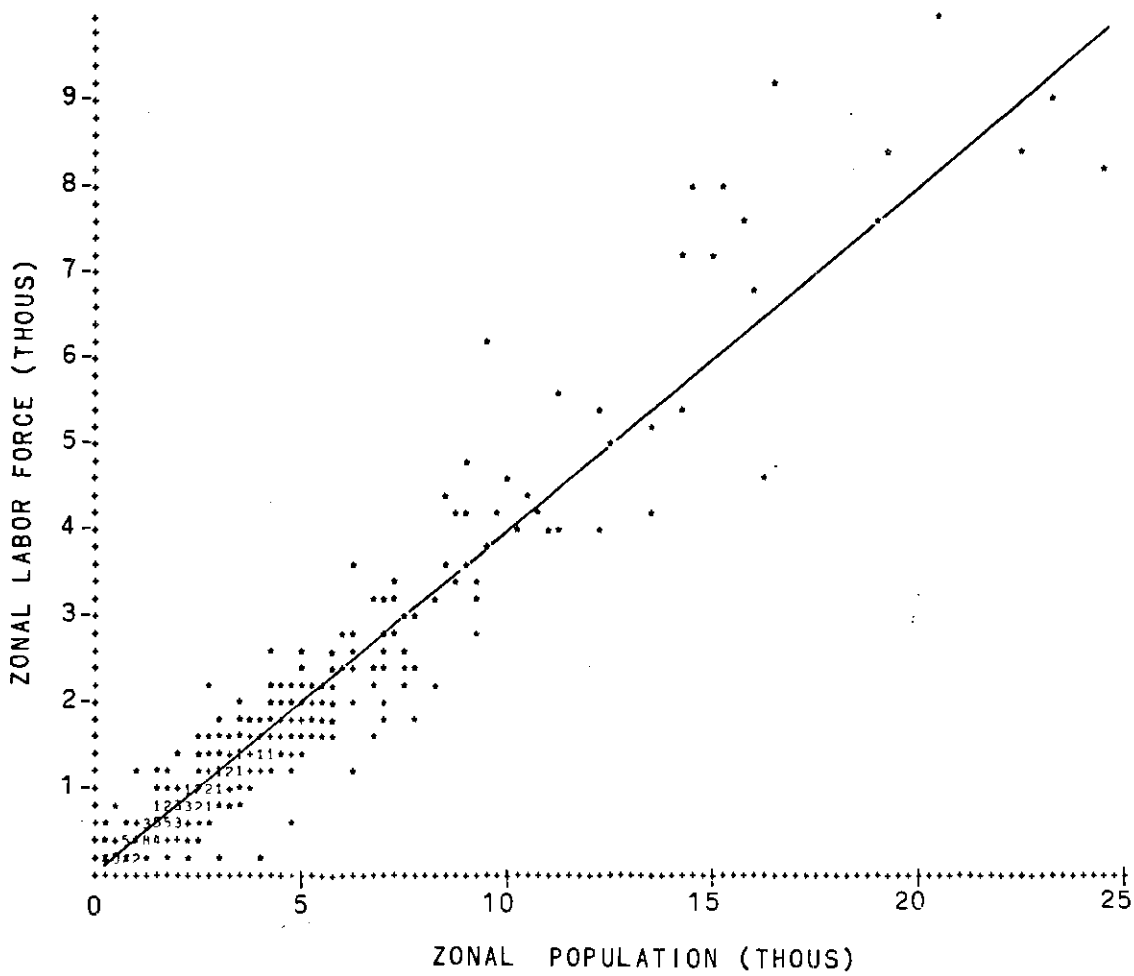
Figure 51. All Modes Total To- Trips



Correlation Coefficient (R)........... 0.947
Coefficient of Determination (R^2)..... 0.897
Standard Error of Estimate............ 0.239
F-ratio............................... 18774

Figure 52. Zonal Car Ownership

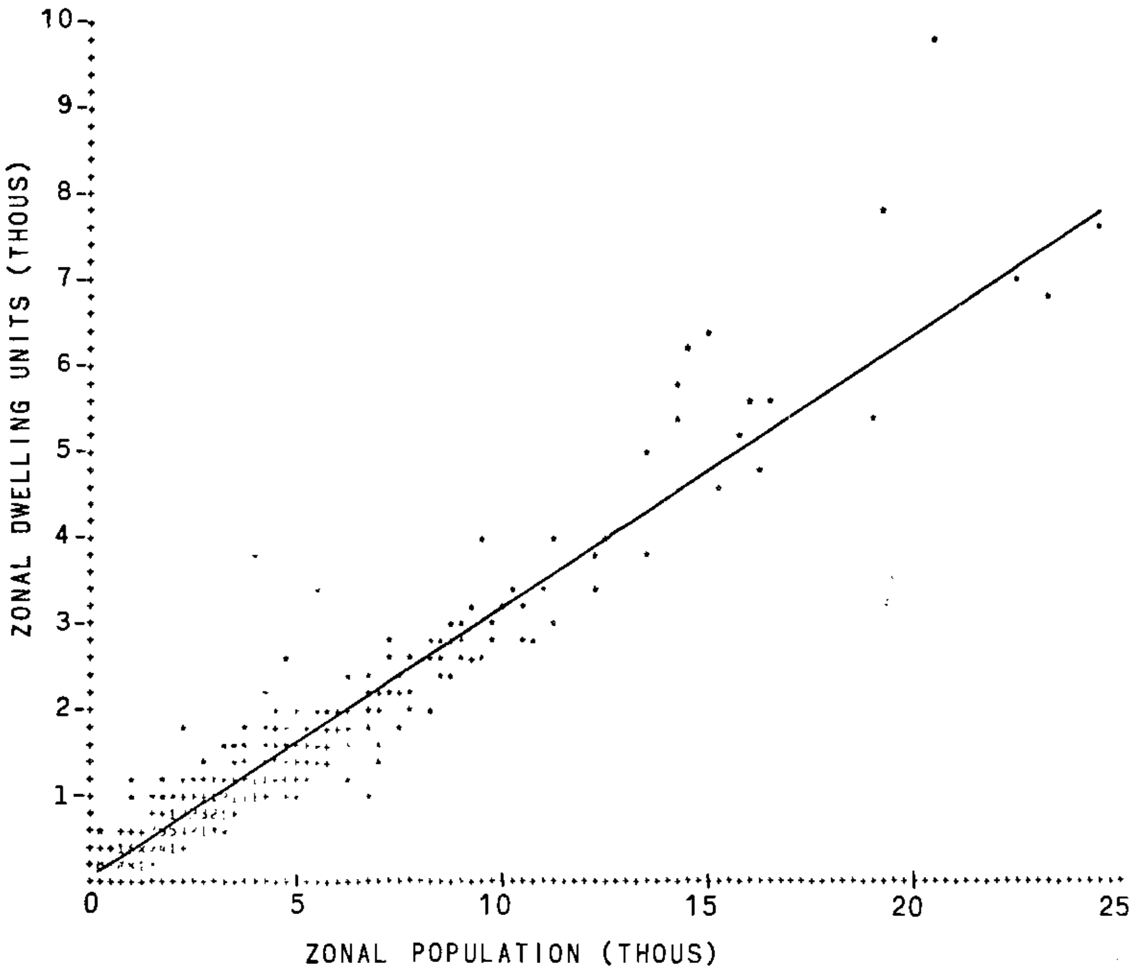
$$Y = -0.044 + 0.401(X)$$



Correlation Coefficient (R)...........	0.972
Coefficient of Determination (R^2).....	0.945
Standard Error of Estimate............	0.228
F-ratio...............................	33416

Figure 53. Zonal Labor Force

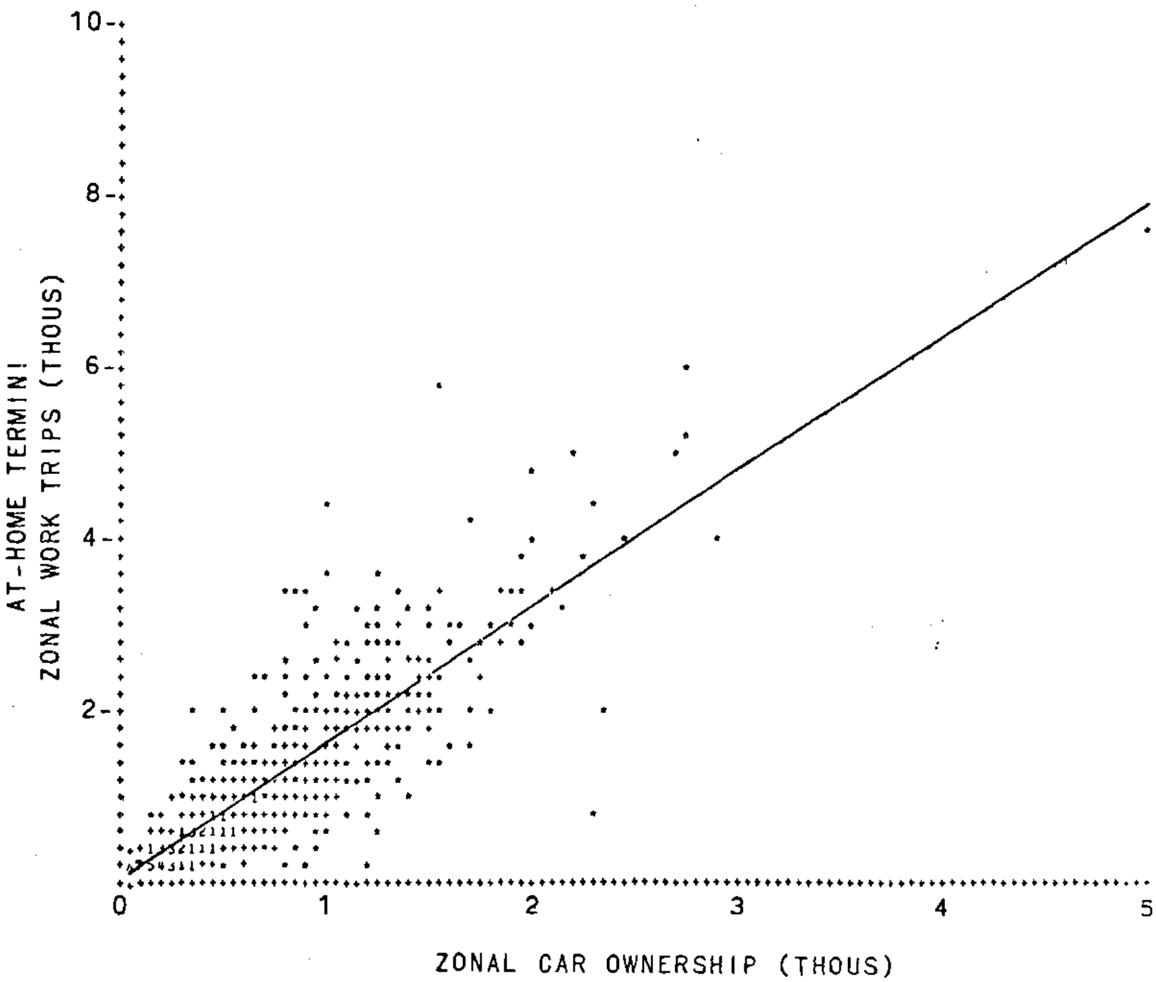
$Y = -0.02 + 0.32(X)$



Correlation Coefficient (R)........... 0.971
Coefficient of Determination (R^2)..... 0.943
Standard Error of Estimate............ 0.180
F-ratio............................ 35677

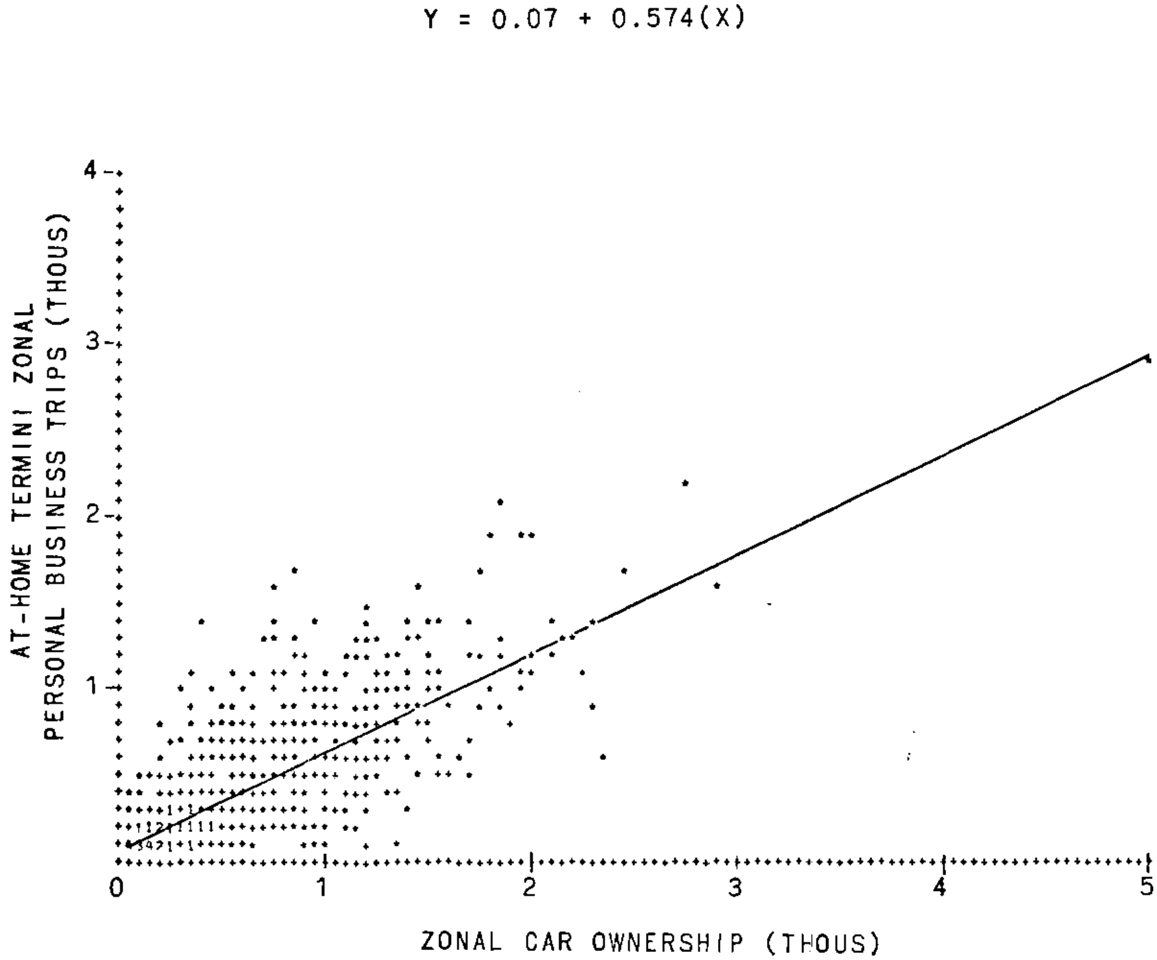
Figure 54. Zonal Dwelling Units

Y = -0.015 + 1.578(X)



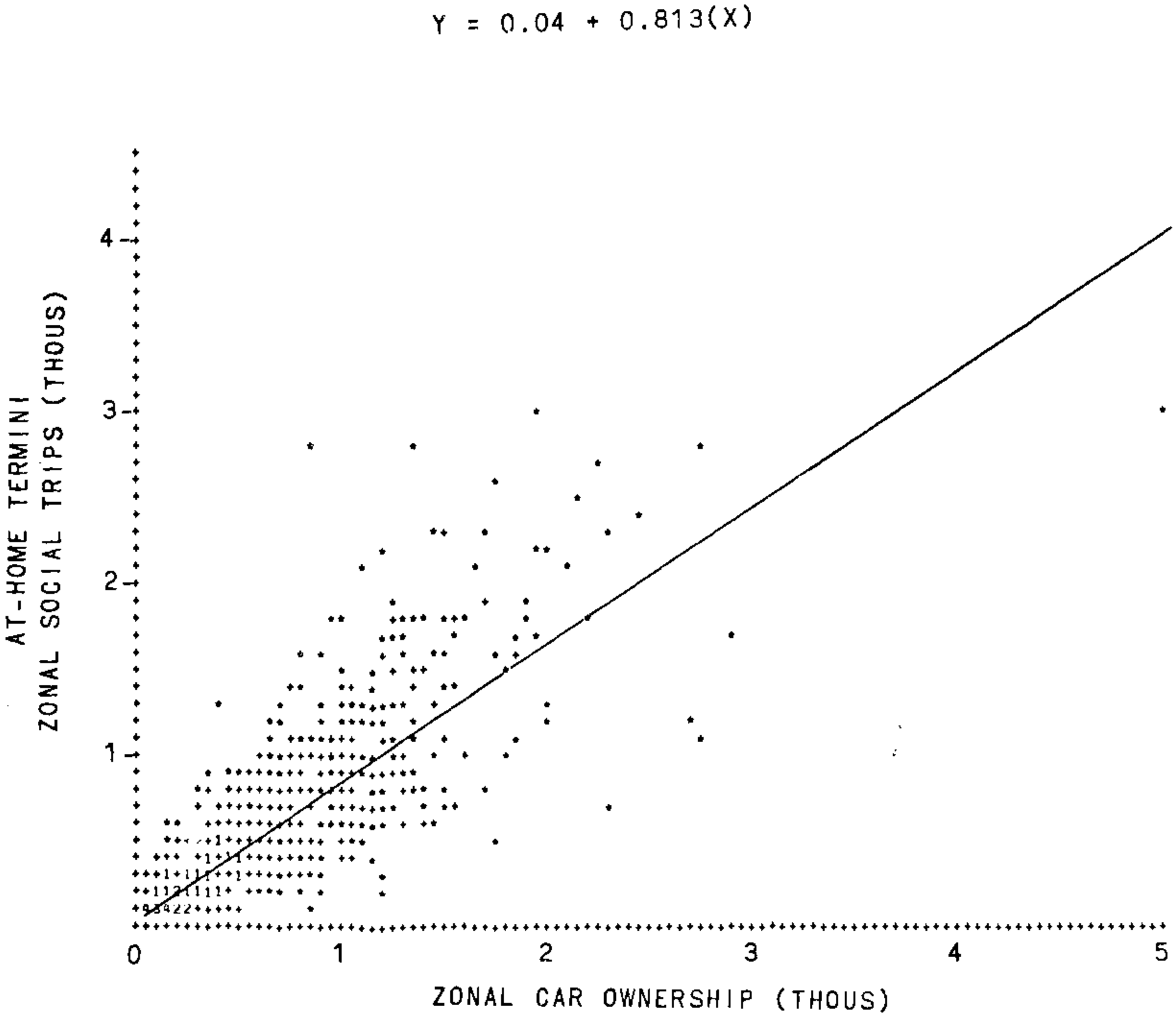
Correlation Coefficient (R)........... 0.898
Coefficient of Determination (R^2)..... 0.806
Standard Error of Estimate............ 0.377
F-ratio............................ 6035

Figure 55. Zonal Work Trips



Correlation Coefficient (R)...........	0.796
Coefficient of Determination (R^2).....	0.633
Standard Error of Estimate............	0.222
F-ratio..............................	1997

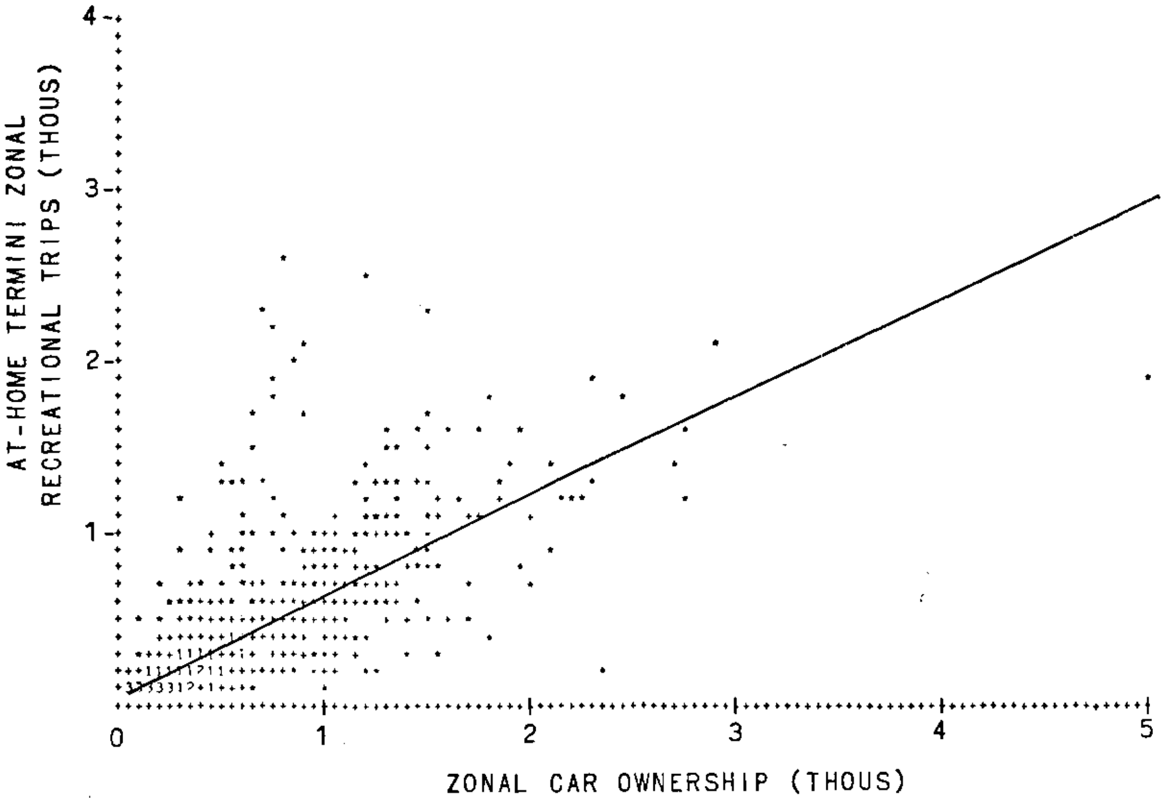
Figure 56. Zonal Personal Business Trips



Correlation Coefficient (R)........... 0.838
Coefficient of Determination (R^2)..... 0.702
Standard Error of Estimate............ 0.275
F-ratio............................... 2725

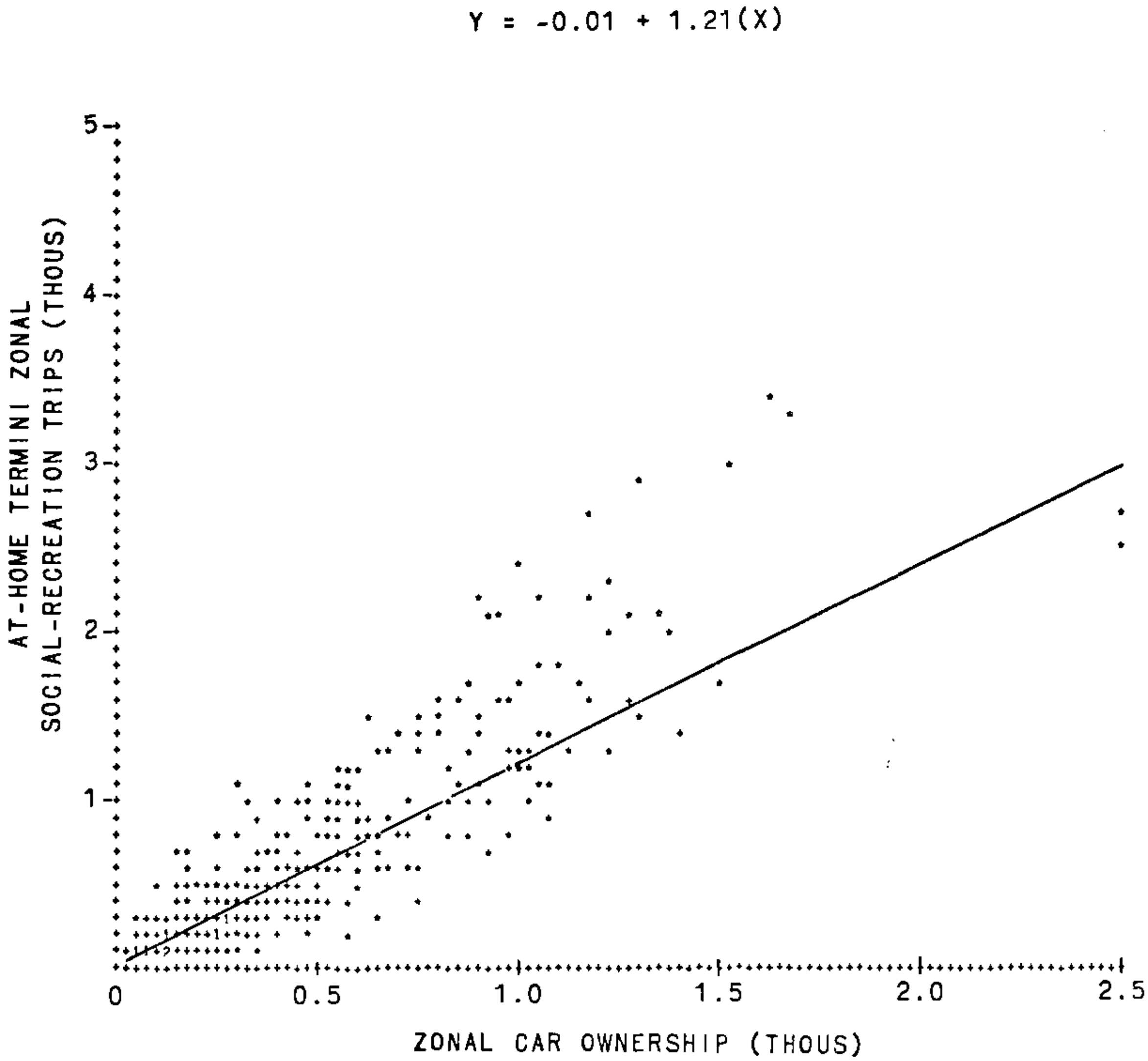
Figure 57. Zonal Social Trips

Y = 0.011 + 0.58(X)



Correlation Coefficient (R)........... 0.840
Coefficient of Determination (R^2)..... 0.705
Standard Error of Estimate........... 0.195
F-ratio............................ 2758

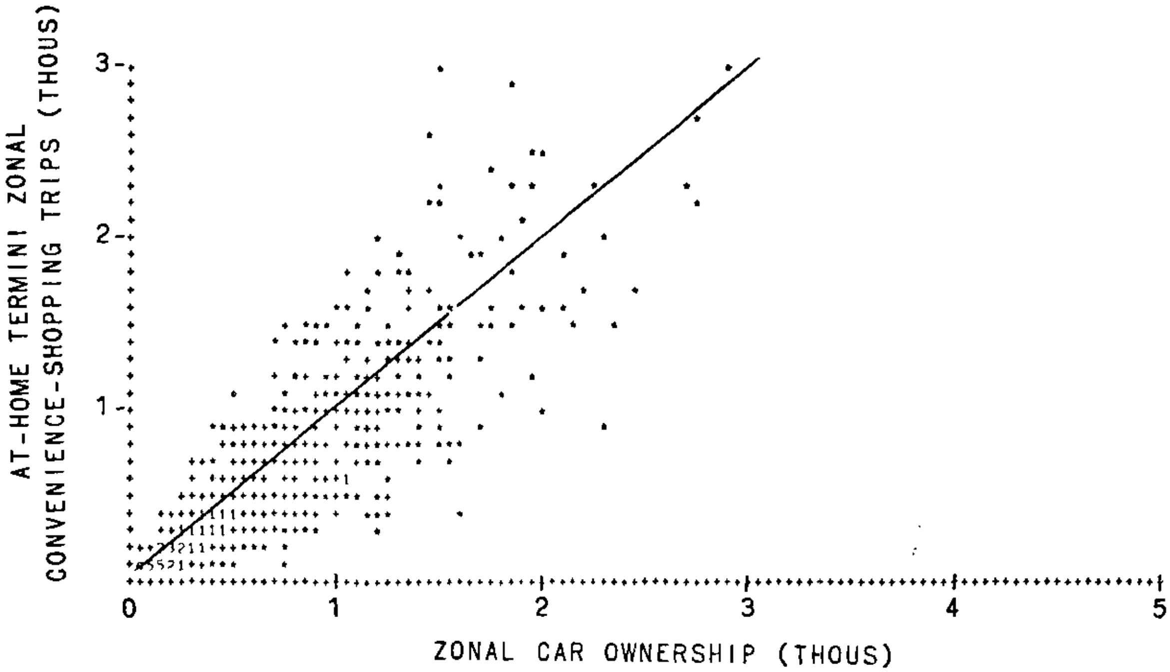
Figure 58. Zonal Recreation Trips



Correlation Coefficient (R)........... 0.917
Coefficient of Determination (R^2)..... 0.841
Standard Error of Estimate............ 0.180
F-ratio.............................. 2511

Figure 59. Zonal Social-Recreation Trips

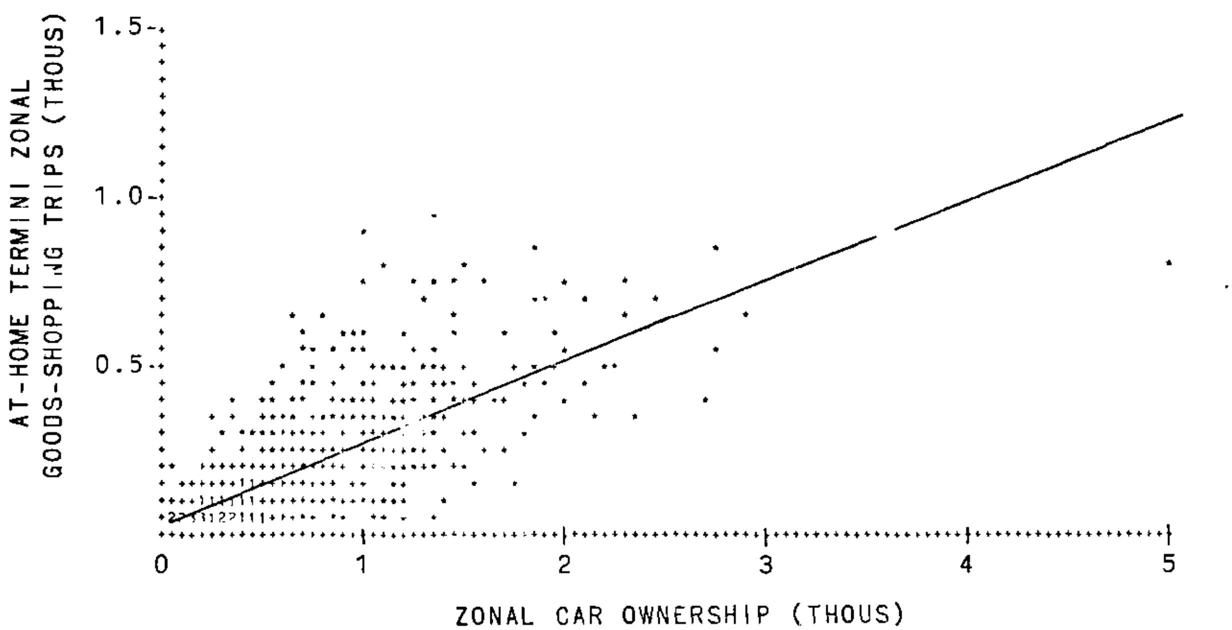
$Y = -0.01 + 0.997(X)$



Correlation Coefficient (R)...........	0.898
Coefficient of Determination (R^2).....	0.806
Standard Error of Estimate............	0.170
F-ratio...............................	3450

Figure 60. Zonal Convenience Shopping Trips

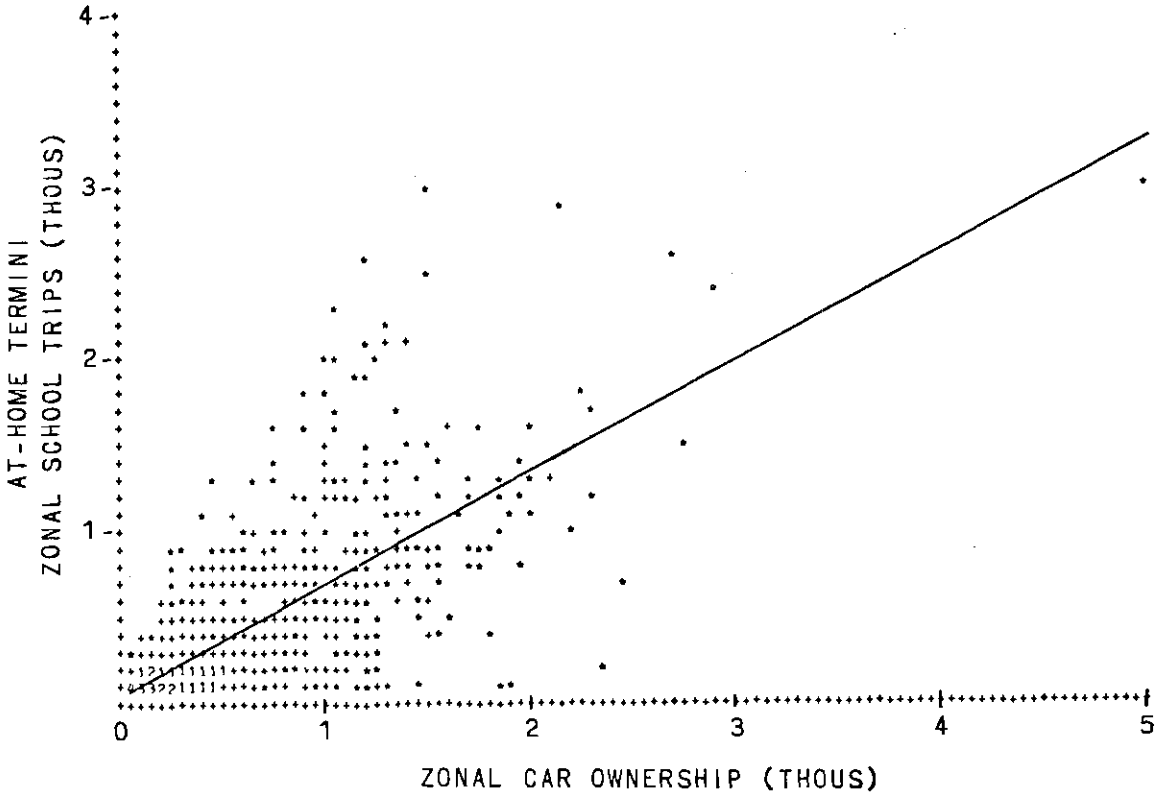
$Y = 0.01 + 0.25(X)$



Correlation Coefficient (R)........... 0.792
Coeff··ient of Determination (R^2)..... 0.627
Standa.. Error of Estimate........... 0.100
F-ratio............................. 1938

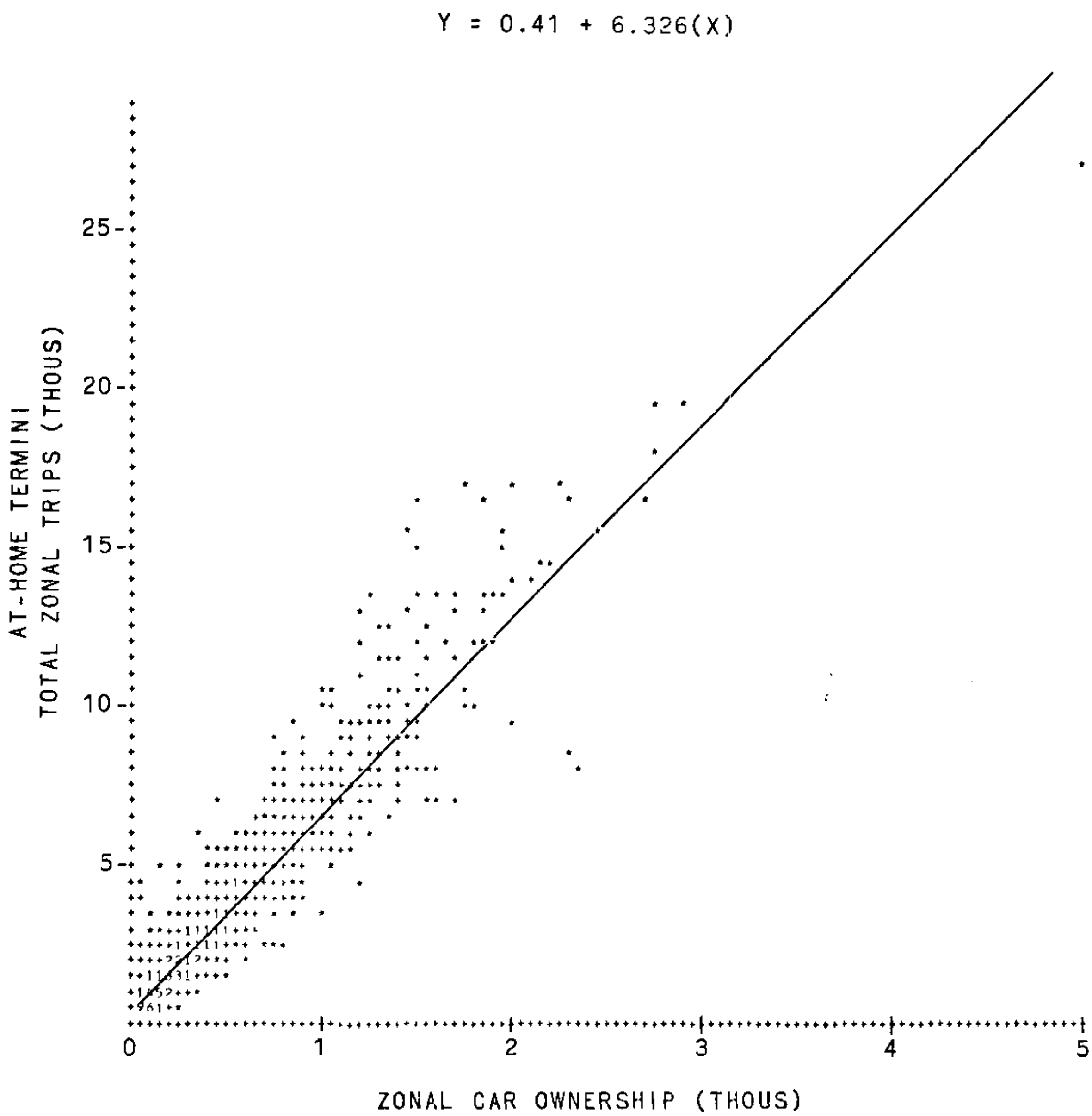
Figure 61. Zonal Goods Shopping Trips

$$Y = 0.008 + 0.653(X)$$



Correlation Coefficient (R)...........	0.737
Coefficient of Determination (R^2).....	0.544
Standard Error of Estimate............	0.290
F-ratio...............................	1729

Figure 62. Zonal School Trips



Correlation Coefficient (R)...........	0.937
Coefficient of Determination (R^2).....	0.878
Standard Error of Estimate...........	1.15
F-ratio..............................	10440

Figure 63. Zonal At-Home Termini Total Trips

APPENDIX B

In Chapter V the choice of the equation of best fit was indicated to be of the form $Y = a + bX$. This is the result of two studies which were performed.

The first study was that of comparing the results obtained by attempting to fit a linear and non-linear equation to the data. Looking at the data plotted in Figures 10 through 51 the choice of an equation of "best fit" of the form $Y = a + bX^n$ for values of "n" greater than zero and less than one might be considered reasonable. The value of "n" equal to zero would not yield as good a "fit" as for n-values greater than zero. The value of "n" greater than one, say $n = 2$, causes the curve to take on a shape contrary to that indicated. A choice of the equation $Y = a + bX + cX^2 + dX^3 + \ldots + iX^k$ where "k" is equal to the number of observations minus one would most certainly "fit" perfectly. The justification of such a choice would not, however, be possible.

Table 30 illustrates the results of the study in question for two choices of the value of "n". Standard regression-correlation techniques were utilized to secure the values given in Table 30.

The headings of Table 30 with respect to values of "n" and "b" agree with those values described in the equation of the form $Y = a + bX^n$ while the value of S.E.E. is the standard error of the estimate. The terms R, R^2, and F are described in Table 23.

In attempting to choose the "best" equation of those presented in Table 30 the argument of which attributes would describe the "best" equation was raised. Statistically speaking the method involved setting the null hypothesis that the curves resulting from the two values of "n" were different from each other, that is, were not the same curves. The alternate hypothesis would then follow to be that the two curves could not be shown to be different from each other. For each set of data illustrated in Table 30, as well as for Auto Passenger trips to seven destinations, a plot of both curves was made. It was found, in every case tested within the population limits imposed by the available data, that both curves fell not only within the hyperbolic envelope located by standard regression techniques about the linear function, but they both fell within parallel lines to the linear function drawn at a distance of two standard deviations. With this graphic illustration it was concluded that the null hypothesis should be rejected and that the evidence failed to show the dissimilarity between the two descriptive equations proposed.

On the basis of judgment it must be argued that the ultimate use of the equations must be considered. Within what limits of accuracy will the equations be used? With

Table 30. Comparison of Linear and Non-Linear Equations of Best Fit for Auto Driver Trips to Various Destinations

Auto Driver Trips	n	b	R	R^2	S.E.E.	F
To Home	0.50	0.53	0.989	0.979	24.1	732
	1.00	0.36	0.987	0.974	26.5	600
To Work	0.50	0.35	0.989	0.979	25.0	722
	1.00	0.23	0.984	0.969	19.0	493
To Pers. Bus.	0.50	6.54	0.962	0.925	5.7	199
	1.00	0.44	0.955	0.912	6.1	167
To Soc.-Rec.	0.50	12.67	0.926	0.857	15.8	96
	1.00	0.08	0.883	0.780	19.6	57
To Shopping	0.50	14.23	0.984	0.970	7.7	52
	1.00	0.09	0.959	0.919	12.5	18
To Other	0.50	17.34	0.978	0.956	11.3	336
	1.00	0.11	0.946	0.894	17.6	135
Total To- Trips	0.50	138.76	0.990	0.980	60.0	800
	1.00	0.93	0.977	0.954	92.0	331

respect to transportation planning either of the equations fall within the required limits of accuracy. On this basis the linear equation would be the choice due to its ease of computation and simplicity.

The second argument in choice of descriptive equation concerned the utilization of a single variable equation or a multivariable equation. On a zonal basis within urban areas there are many attributes measured. They generally include population, population greater than five years of age, population greater than five years of age making trips, dwelling units owned, dwelling units rented, total dwelling units, car ownership, labor force, employment, number of licensed drivers, number of school aged children, residential acreage, income level, cars per dwelling unit, distance from the CBD, total person trips, auto driver trips, auto passenger trips, retail sales, commercial acreage, trips by purpose to the CBD, among others. Since these attributes are quantified on a zonal basis they can be summarized on an urban area basis. It was decided to investigate as many of these attributes as possible in an attempt to discover the interrelationships among and between the attributes. All of the attributes listed above were not given on a zonal basis in all of the studies utilized in this research. An attempt was made to maximize the number of attributes without minimizing the number of urban areas involved in the study. Two investigations resulted, one utilizing six urban areas and a second involving eight urban areas. From a statistical study of one hundred zones chosen at random from six urban areas the following three groups of data were determined on the basis of high correlations within each group.

Group 1. Size

Population
Population greater than five yrs. age
Pop'n greater than five yrs. age
making a trip
Dwelling units owned
Dwelling units rented
Total dwelling units
Car Ownership
Labor force
Number of licensed drivers
Total number of trips
Number of auto driver trips
Number of auto passenger trips

Group 2. Income

Income level
Cars per dwelling unit
Trips per person

Group 3. Economy

Retail Sales

From a subsequent statistical analysis of 125 zones chosen at random from eight urban areas the following three groups of highly intercorrelated attributes were discovered.

Group 1. Size

Population
Labor force
School aged children
Car ownership
Dwelling units
Residential acreage
Total person trips to the CBD
Auto vehicle trips to the CBD
Transit trips to the CBD

Group 2. Income

Income level
Distance from the CBD
Truck passenger trips to the CBD

Group 3. Economy

Retail Sales
Commercial acreage
Employment
Taxi trips to the CBD

It was assumed that characteristics which tended to define some zonal attribute in an urban area might also tend to describe the same attribute on an urban basis. Statistical analyses were performed on the urban level and the results seemed to indicate that two groups of attributes emerge from approximately twenty attributes commonly measured in origin-destination studies. The two groups are size and income. This point is illustrated in Table 5.

With but two attributes which are not highly correlated on an urban level an equation of the form

$$Y = a + bX_1 + cX_2$$

where X_1 = population and

X_2 = median income

was fitted to the Auto Driver trips to seven various destinations. The contribution of the term involving median income was negligable as illustrated in Table 31.

After studying the effect of the addition of the median income attribute it became apparent that the inclusion of such an attribute would lend little to the

Table 31. Comparison of Single Variable and Multivariable Equations of Best Fit for Auto Driver Trips to Various Destinations

Auto Driver Trip	a	b	c*	R^2
To Home	13.66	0.450	0	0.979
	13.57	0.441	0.02	0.984
To Work	3.61	0.308	0	0.990
	7.82	0.299	0.017	0.992
To Pers. Bus.	12.23	0.054	0	0.761
	-1.10	0.053	0.031	0.840
To Soc.-Rec.	4.32	0.140	0	0.847
	6.46	0.137	0.002	0.870
To Shopping	9.30	0.140	0	0.912
	5.14	0.136	0.010	0.931
To Miscellaneous	9.87	0.181	0	0.918
	11.23	0.174	0.004	0.923
Total To- Trips	53.0	1.268	0	0.970
	72.2	1.245	0.077	0.975

* For c-values of zero the equation of the form $Y = a + bX$ is indicated.

validity of the single variable equation. On the surface it would seem that there is an inordinate amount of over-collection of data being required by the sponsoring agencies with respect to origin-destination studies. Secondly, a need for collection of other data which might not be population or size dependent appears to be most strongly in order.

APPENDIX C

DESCRIPTION OF ANALYTICAL TECHNIQUES

Reference was made in Chapter III to the use of standard regression-correlation techniques for analysis of data. The purpose of this appended section is to provide a more detailed accounting of the methodology of data result analysis as it applied to the research as well as to outline the data analyses procedures utilized.

Statistical methods do not possess the quality of revealing anything that is not implicit to the set of data being analyzed. They cannot manufacture additional data or insure the success of extrapolation beyond the limits of the data. In the analysis of data which is simple in structure and quantity the judgement of the researcher will generally lead him to the same conclusions irregardless of whether standard statistical techniques are utilized. In the analysis of data which are complex in structure and voluminous in quantity, statistical technique affords the researcher the luxury of sorting procedures which clarify that which is implicit in the data. In addition, statistical procedure does allow the researcher the opportunity to limit personal prejudices and bias in the evaluation of data.

The general procedure used in evaluating the input data for this thesis was as follows:

(1) As a preliminary screening measure, all available data were subjected to simple correlation analyses in order to discover where similarities might exist.

(2) Where high correlations existed between any two variables the logic of the relationship was argued. If, based on subjective judgement, the two variables were related, the relative dependency or independency of one upon the other was argued.

(3) Assuming that the two variables could be categorized as argued, a plot of the two variables was made to determine, by subjective judgement, the probable graphical relationships displayed. If, however, the two variables could not be so categorized (for example, a high simple correlation is exhibited between the population of an urban area and the number of dwelling units which are owned within that urban area, but a third attribute, that of total dwelling units in an urban area can be argued to be the link between population and owned dwelling units.) a relationship between each of them and a third highly correlated variable was studied. This would result in returning to step #2 of this procedure for further analysis. This phase of data analysis is discussed later under the "Reasonableness of Results" heading.

(4) After studying the graphical display between two highly correlated variables two points were argued: (A) the choices of mathematical expressions which were to be compared in describing the indicated relationship and (B) the validity of the standard assumptions required for the statistical analysis tool to be utilized.

(5) After choosing the mathematical expressions to be tested, and based on subjective judgement, and satisfying the standard assumptions associated with the statistical procedure chosen, the data were analyzed and various measures of statistical validity were determined. These measures are discussed later under the subject of "Statistical Validity".

(6) The choice of the best mathematical expression was then made based on judgement, proposed use of the expressions, reasonableness of results and statistical validity. These topics are discussed hereinafter.

Regression

Regression analysis is defined by various authors (61, 62, 63, 64, 65) to be a statistical procedure in which two or more variables can be mathematically expressed. The basic assumptions made in utilizing regression analysis on a set of X-Y data are defined in a succinct manner by Winer (66) as well as by other authors (63, 64, 67) in a set of statements which lend themselves to categorization as follows:

(1) In the set of statistics (X_i, Y_i) for i = 1, 2...,n observations, Y_i is a random variable and X_i is an observation taken without error.

(2) For a given value of an independent variable (X_i) there exists a set of variables (Y_i) which are distributed normally and independently.

(3) The principle of homoscedasticity holds true. (The variance, σ^2, of all sets of the Y-values is the same.)

(4) The error (ϵ) which exists due to estimating the dependent variable is distributed in a normal and independent sense with a mean value of zero and a variance equal to σ^2.

The mathematical expression can take on any form. The primary form utilized in the research was linear. Other forms were utilized also. For the linear case the equation

$$Y^* = A + B(X)$$

was chosen as the estimated regression of Y on X wherein the value of Y* is the estimate of the dependent variable,

A is the Y-axis intercept,

B is the slope of the regression line,

X is assumed to be determined without error and

Y is an observed value of the assumed dependent variable.

In the area of this research where multiple regression was utilized the equation of the form

$$Y^* = A + B_1X_1 + B_2X_2$$

was chosen wherein more than one independent variable was utilized in the estimation of Y.

The object of the analysis is to minimize the expected error involved in estimating the dependent variable by determining the "best" values for the terms "A" and B_i in the regression equation. Such an objective is achieved through the use of the method called "least squares" in which

$$\sum_{i=1}^{n} (Y_i - Y_i^*)^2 \text{ is minimized.}$$

Failure to meet the specifications for the basic assumptions regarding regression analysis previously discussed can seriously affect the validity of the statistical measures derived (see "Statistical Validiey" section). The capability of absolute adherence to the assumptions is questionable for any set of data which are influenced by socio-economic characteristics. The capability of strictly meeting the test of absolute dependence or independence is not possible. There is, however, the opportunity of arguing the use of the statistical techniques in light of the limitations imposed by nonability to meet fully the requisites of the basic assumptions. Within the accuracy required in the field of transportation planning one can attempt to argue for the use of tools which help sort out the myriad of data involved.

Correlation

The method of correlation, according to Peatman (65) and Winer (66) is a method for determining how well the regression equation "explains" the relationship between the independent variable(s) in the equation and the dependent variable. This determination is made through use of a statistic known as the coefficient of determination (R^2). The correlation coefficient is the square root of the coefficient of determination.

The relationship or association between any two variables can be measured in terms of a simple correlation coefficient. Thus, its use is not limited to its application in a regression analysis technique. However, when it is applied to a simple regression equation it is a measure of the linear relationship between the dependent and independent variables. In the case of the linear relationship between a dependent and independent variable as utilized in regression analysis, the coefficient of determination can be shown (66) to be

$$R^2 = \frac{\sum_{i=1}^{n} (Y^* - \overline{Y})^2}{\sum_{i=1}^{n} (Y_i - \overline{Y})^2}$$

Worthing and Geffner (68) state that the simple correlation coefficient is a function of the ratio

$S_{Y'}:S_Y$ where $S_{Y'}$ is the standard deviation associated with the estimated Y-values and S_Y is the standard deviation described by the observed Y-values.

The value of R^2 will vary between zero and one depending on the variance which is left unexplained by the independent variable in the regression equation. Even if a high value of R^2 occurs for a regression equation, a correspondingly high degree of dependence does not follow. As an example, the coefficient of determination which exists between zonal taxi trips to the CBD and zonal commercial acreage was found to be high within the urban areas studied. The reasonableness of this relationship is most difficult to defend. On the other hand, a low value of R^2 may not mean there is no correlation evident, only that there is no linear correlation present. In the final evaluation one must consider that judgement must be exercized in evaluating the reasonableness of the inferred association.

Statistical Validity

There are several statistics which can be utilized in attempting to ascertain the statistical validity of a proposed regression equation. A discussion of those used in this thesis is as follows.

A statistic which illustrates the degree of association between the independent and dependent variable in a regression equation is the correlation coefficient. It is generally stated that, as the value of "R" approaches one, the reliability of the inferred association increases. The reasonableness of the association must be ascertained prior to accepting the value as meaningful.

The standard estimate of error is defined by Peatman (65) for a linear regression to be a measure of the dispersion of the observed data points (Y_i) about the regression line described by an equation of the following form:

$$Y^* = A + B(X_i)$$

The standard estimate of error indicates the degree of variation of the observed data points. Winer (66) states that it is a measure of the expected error in predicting the dependent variable from independent variables in the regression equation.

The F-ratio is a value associated with the Analysis of Variance procedure. In Hicks' discussion of the fundamentals of analysis of variance (69) he lists the assumptions which underlie the procedure to include the requisites that "the random errors involved were sampled from a normal universe, the data must exhibit homoscedasticity and linear models must be used so that the effect of all factors is additive." Further, he states that, the higher the F-ratio value, the more significant is the slope of the regression line. The F-ratio value is closely akin to the t-ratio value wherein one can compute the probability that an observed coefficient of regression might have been obtained by chance in random sampling from a population in which the true coefficient of regression was actually equal to some other value. Anderson (70) states that the F-ratio is a ratio of two variances and for simple linear regression the relationship between t and F is as follows:

$$t^2 = F$$

Thus, one can conclude that, as the F-ratio increases, the probability that the regression coefficient is equal to one decreases.

The matrix of simple correlation coefficients exhibits the simple correlation coefficients for all combinations of variables, be they dependent or independent. This type of table must be prepared as the first step in the analysis of data such as are evaluated in this thesis. An examination of such a matrix is an invaluable aid in helping the researcher develop insight into relationships between variables.

One method for determining statistical validity which is rarely reported in the literature is the graphical presentation of data _prior_ to regression analysis so that prejudice in choice of mathematical expressions can be minimized. There is probably no better tool for the analyst in helping to evaluate the validity of his proposed mathematical expression.

Reasonableness of Results

In attempting to define the relationship which might exist between any two variables the statistical procedure is the tool which reduces the complexity of the data and allows an analyst to spend his time more wisely, that is, in the evaluation of the statistical output and in the determination of its relevency. In the evaluation of the terms utilized in a mathematical expression which is purported to quantify a demendent variable in terms of an independent variable the relationship between the variables must be established with respect to several characteristics. These characteristics include simplicity, forecastability, maintenance of stability, logic in relationship, causitiveness, meaningfulness in contribution and logic in such contribution. The evaluation of these characteristics is the most vital phase associated with the development of mathematical expressions similar to those hereinbefore presented.

Simplicity

The primary reason for attempting a forecast of one variable in terms of other variables should be to reduce the amount of data collection necessary in the first place. The more simply structured the required data, the more acceptable the collection of such data will become in terms of expenditure of time and money.

Forecastability

Trip generation equations should contain only those variables which are assumed to be primarily independent which can be forecast within a degree of accuracy which is reasonable. The value of the expression is, by logical argument, no more precise than the input to the equation.

Maintenance of stability

The assumption of stability over a period of time is generally made in expressions which deal with forecasting one variable in terms of others. It is most important that the variables assumed to be independent possess the quality of stability with respect to time. The researcher must keep this goal in sight so that meaningful forecasts will follow meaningful judgement decisions.

Logic in relationship

A logical relationship between the variables which are included in the mathematical expressions must be defensible. It is quite important that illogical variables, which appear to be independent and highly related to the one being defined, be removed from consideration prior to data evaluation.

Causitiveness

As discussed earlier in this Appendix (page 139) some variables may enter into association with other variables by chance. In order to insure a meaningful descriptive equation some degree of trust must be placed in the causitive nature of one variable on another assuming an association is implied.

The situation of a noncausitive variable entering into an expression generally occurs when a researcher allows the regression procedure to mechanically search the data for relationships of a numerically "satisfactory" nature.

Meaningfulness in contribution

It is not necessary to describe one statistic which is assumed to be primarily dependent in terms of many statistics which are assumed to be principally independent for the sake of attaining a very high degree of relationship. In the transportation planning process it is recognized that forecasts are being made with a certain degree of inaccuracy. This point is illustrated in Table 31, Appendix B.

Logic in contribution

Several points of interest occur under this categorization with respect to transportation planning trip generation equations. Intermixing zonal rates and aggregates in the same equation should be avoided, if possible. The rate variable eliminates the size of the zone while the aggregate variable does not. This would result in a zone which has little development carrying a weight equivalent to a zone which has much development. The reasonableness of the constant in a regression equation must also be argued. When the constant term contributes the majority of the estimate of the dependent variable it may cause difficulty. This is not to infer that large constants are necessarily unsafe, only that the researcher should be aware of the potential gross inaccuracies possible in the estimated value. The positive or negative contribution fixed by the independent variable should be strongly examined. If a negative contribution is indicated the consistency of the contribution with logic must be ascertained.

The seven characteristics discussed above are not statistical procedures which lend themselves to quantification. They are, however, an integral part of the totalized concept of developing mathematical expressions defining one attribute in terms of other attributes. These value judgements are unto themselves unique analytical techniques which must necessarily form the foundation in trip generating equations in the transportation planning picture. Through the proper use of standard statistical techniques such as regression and correlation an analyst can quantify various attributes in terms of other attributes. Through the proper use of analytical techniques involving judgement decisions an analyst can lend credence to his quantifications.

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VITA

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He attended the University of Miami and Florida State University prior to entering the U. S. Army in 1952. After serving with the Corps of Engineers in the Army he returned to the University of Miami in 1955. After being awarded a BSCE from the University of Miami in 1958 he joined the Florida State Road Department. He joined the faculty at Purdue University as an instructor in 1959 and completed work toward the MSCE at Purdue University in 1961. He joined the faculty of the University of Miami at that time and currently holds the rank of Associate Professor of Civil Engineering at that institution.

Abstract

Trip Production in Urban Areas

William J. Fogarty

158 Pages

Directed by Dr. Paul H. Wright

The research was performed in order to develop trip production equations for urban areas. In developing the equations, data were utilized from approximately fifteen urban areas. These data were taken from recent Origin-Destination studies completed in the respective urban areas.

Equations describing the To- and From- trips for several purposes (Home, Work, Personal Business, Shopping, Social-Recreation, Miscellaneous and Total) by several modes (Auto Driver, Auto Passenger, Taxi Passenger, School Bus Passenger, and All Modes) were developed on an urban basis utilizing standard regression-correlation techniques. High degrees of correlation were found for most equations.

Equations descriptive of At-home Termini trips for several purposes (Work, Personal Business, Goods Shopping, Convenience Shopping, Social, Recreational, School, and Total trips) on a zonal basis were developed using standard regression-correlation techniques. High degrees of correlation were found for most cases in question.

One of the primary findings of this study was that an inordinate amount of overcollection of socio-economic data is being required in Origin-Destination studies. In addition, it was found that population is a strong indicator of the propensity of large groups of people to participate in vehicular travel. Trip numbers can be estimated with respect to trip purpose within the population range of 50,000 to 800,000 with high degrees of correlation.

On a zonal basis within the urban area the accuracy of estimating trip production is not as good as on an urban basis. However, the accuracy of such estimates on a zonal level is within the range desired by most transportation planning studies.

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